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Bulk Data Analysis With Optimistic Decoding and Sector Hashing

Garfinkel, Simson L.

Monterey, California. Naval Postgraduate School

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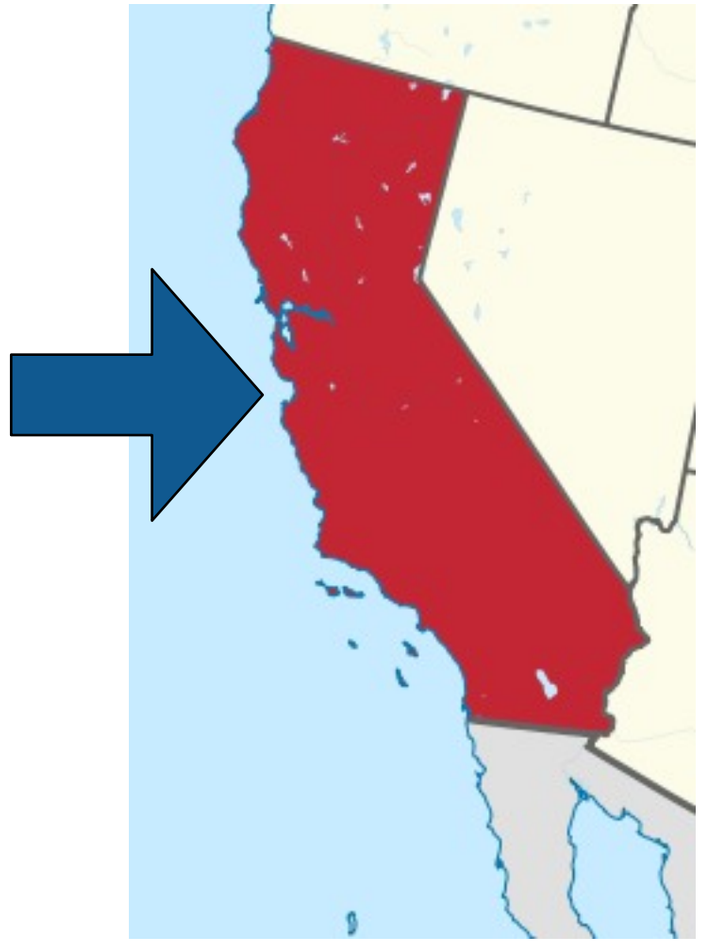
USNA

Simson L. Garfinkel
Associate Professor, Naval Postgraduate School

http://simson.net/

NPS is in Monterey.
I am based in Arlington.

Monterey, CA



National Capital Region (NCR) Office

- 900 N Glebe (Ballston)/Virginia Tech building
  ARLINGTON, VA

My research focus: better tools and algorithms for triage.

Identification of high-value data.

- What is important?
  - *Contacts, calendar, documents?*
  - *Software?*
  - *Geolocation information?*
  - *Temporal / time sequence?*

Correlation — are there copies of the *same* or *similar* information?

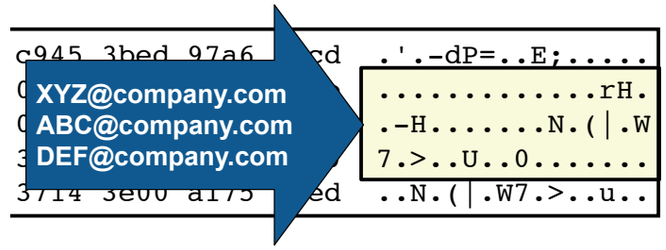
- Identify previously unknown *organizations* or *networks*
- Identify data that is *unusual* or *emerging*

Presentation and Integration:

- Make the results *understandable*.
- Effect organizational change through adoption & integration

This talk presents two ideas for “triage” of digital media.

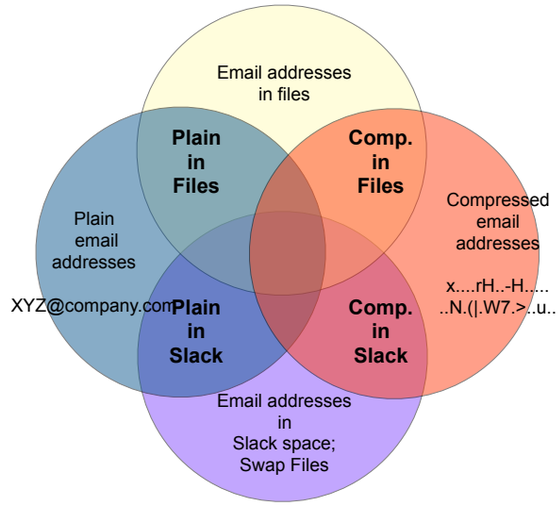
1. Finding identity evidence with optimistic decoding.



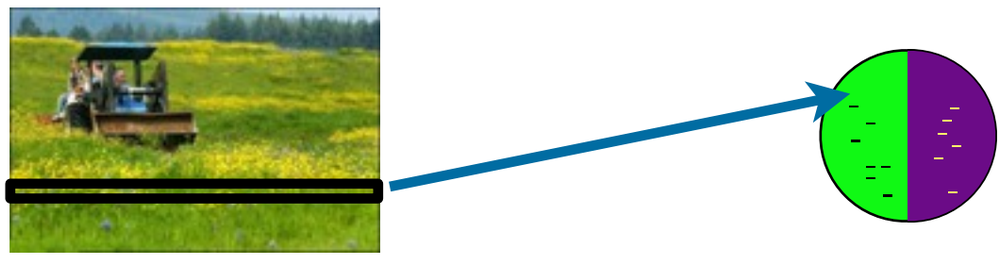
Identity information can be compressed.

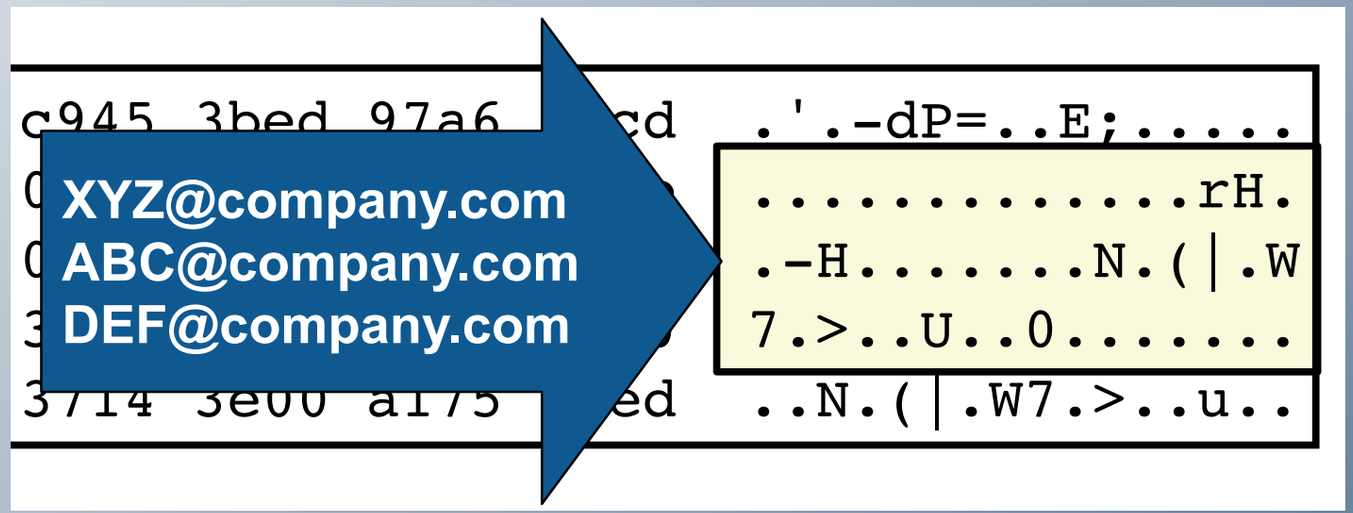
Popular forensic tools do not optimistically decompress.

Our study of 1400 drives found thousands of email addresses that were *only in compressed data.*



2. Sector hashing as a tool for rapid and comprehensive searches.





Finding encoded data with optimistic decoding

Searching for email addresses on media is a common digital forensic task.

Email addresses can reveal:

- User(s) of a device
- Associates
- Connections between devices

ABC@company.com
DEF@company.com
XYZ@company.com

HIJ@network.net
KLM@network.net
NOP@network.net
XYZ@company.com

- Today's forensic tools implement two strategies for extracting email addresses.
  1. *Text extraction from files*
  2. *Text extraction from bulk data*

Many forensic tools use Oracle's "Outside In" to extract text from files.

Outside In will extract text from:

- Word .doc
- Word .docx
- PDFs made by Word
- 600+ other file formats

Folders.pst

Mother.JPG

Presentation.pptx

Sequestration.docx

Outside In only works on files….

Typical computers have data in File and Non-File space.

```
e327 962d 6450 3d91 c945 3bed 97a6 a4cd   .'.-dP=..E;.....
1f8b 0800 0000 0000 0203 8b88 8c72 48ce   .............rH.
cf2d 48cc abd4 03d2 0a8e 4ece 287c 1757   .-H.......N.(|.W
3714 3e00 b455 c1c5 3000 0000 0000 0000   7.>..U..0.......
0a8e 4ece 287c 1757 3714 3e00 a175 10ed   ..N.(|.W7.>..u..
```

Folders.pst

Mother.JPG

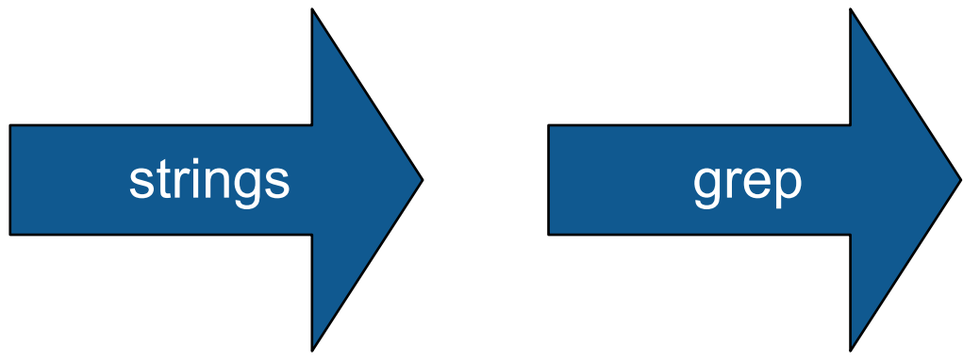
Presentation.pptx

Sequestration.docx

```
a097 83a1 ed96 26a6 3c69 3d0f 750a 2399   ......&.<i=.u.#.
a2b5 bea7 692f 5847 a38a dd53 082c add5   ....i/XG...S.,..
5061 b64c 721d 864b 90b6 b55f bb04 735c   Pa.Lr..K..._..s\
9448 6730 5453 df64 813e b603 5795 2242   .Hg0TS.d.>..W."B
e9c8 7454 7322 7cdc b60e 97af 2f64 2728   ..tTs"|...../d'(
3cfb 84bd 2a84 2dfe 50ea 5935 c349 1513   <XYZ@COMPANY.COM
a9e9 e92c a3f8 6e46 0530 8a88 c7a2 5d2b   ...,..nF.0....]+
d89d 77cc fe1e f637 f3f3 d0af 1b47 c09b   ..w....7.....G..
```

Strings & grep can find email addresses in non-file space.

```
$ strings -t d diskimage.dd | grep '[a-z]+*@[a-z0-9]+'
```



Problems with this approach:

- Slow (not parallelized)
- Many false positives
- Each ‘search’ requires a complete scan of the device
- Misses encoded data.

bulk_extractor is a stream-based disk forensics tool. It extracts email addresses (and more).

0 → 1TB

3 hours, 20 min to *read* the data

1. Read all of the blocks in order.
2. Look for information that might be useful.
3. Identify & extract what's possible in a single pass.

bulk_extractor improves on strings & grep

Finds more kinds of data:

- Structured text (email addresses, URLs, etc)
- Structured binary data (Microsoft Windows PE files, LNK files, etc)

Finds data in many kinds of situations:

- Compressed & encoded data.
- Recursive re-analysis

Expandable:

- Easy to add new features.

“Encoded data” must be *decoded* to be recognized.

Compression removes redundancies in data:

```
5859 5a40 636f 6d70 616e 792e 636f 6d20  XYZ@company.com
4142 4340 636f 6d70 616e 792e 636f 6d20  ABC@company.com
4445 4640 636f 6d70 616e 792e 636f 6d20  DEF@company.com
```

Compressed with “gzip:”

```
1f8b 0800 0000 0000 0203 8b88 8c72 48ce  .............rH.
cf2d 48cc abd4 03d2 0a8e 4ece 287c 1757  .-H.......N.(|.W
3714 3e00 b455 c1c5 3000 0000            7.>..U..0...
```

Compressed email addresses do not “look” like email addresses!

—*Forensic tools must “optimistically” decompress data to search for email addresses.*

The same information can be encoded on the media in many different ways.

A simple Microsoft Word document:

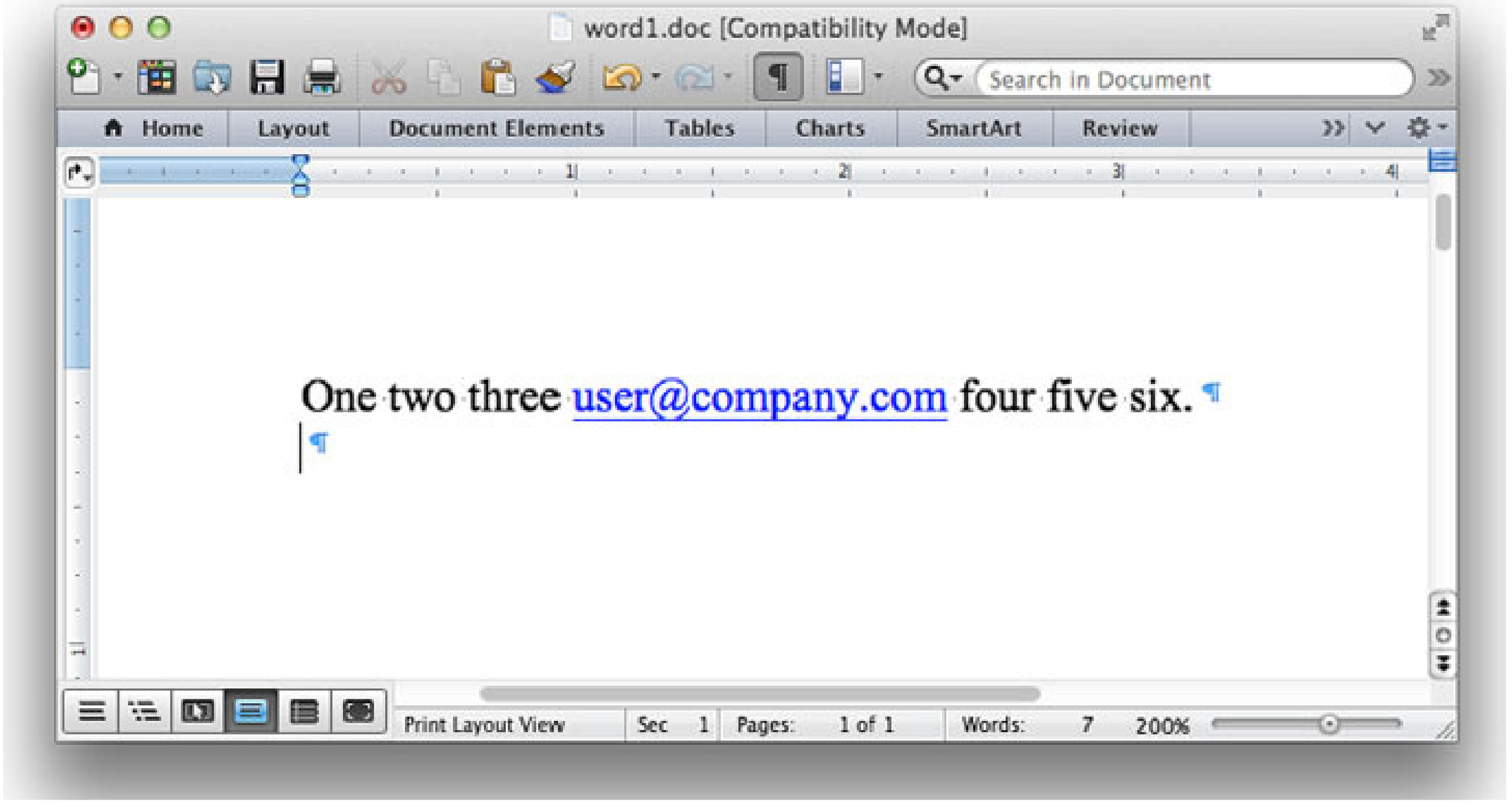
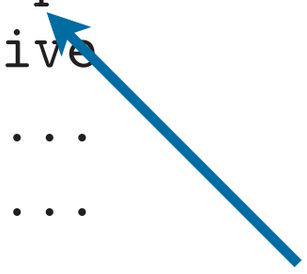


FIG. 1—*A Microsoft Word file containing a single sentence followed by a blank line.*

Word's .doc format stores email addresses as plain text (UTF-8 and UTF-16)

```
00000a00: 4f6e 6520 7477 6f20 7468 7265 6520 1320  One two three .
00000a10: 4859 5045 524c 494e 4b20 226d 6169 6c74  HYPERLINK ‘‘mailt
00000a20: 6f3a 7573 6572 4063 6f6d 7061 6e79 2e63  o:user@company.c
00000a30: 6f6d 2220 1475 7365 7240 636f 6d70 616e  om’’ .user@compan
00000a40: 792e 636f 6d15 2066 6f75 7220 6669 7665  y.com. four five
00000a50: 2073 6978 2e0d 0d00 0000 0000 0000 0000   six.............
00000a60: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000a70: 0000 0000 0000 0000 0000 0000 0000 0000  ................
```



Word's .docx format stores content as compressed XML

```
00000990: 0300 504b 0304 1400 0600 0800 0000 2100  ..PK..........!.
000009a0: ea76 7d78 d702 0000 c607 0000 1100 0000  .v}x............
000009b0: 776f 7264 2f64 6f63 756d 656e 742e 786d  word/document.xm
000009c0: 6ca4 55db 729b 3010 7def 4cff 81d1 7b0c  l.U.r.0.}.L...{.
000009d0: 7673 7198 e034 b7a6 79e8 3453 b7cf 1d19  vsq..4..y.4S....
000009e0: 0468 8cb4 1a49 98ba 5fdf 95b8 d889 ddd6  .h...I.._.......
000009f0: 495e 0c98 b367 cf9e 5d2d 1797 bf44 15ac  I^...g..]-...D..
00000a00: 9836 1c64 42c6 a388 044c a690 7159 24e4  .6.dB....L..qY$.
00000a10: c7f7 4f47 5312 184b 6546 2b90 2c21 6b66  ..OGS..KeF+.,!kf
```

Uncompress

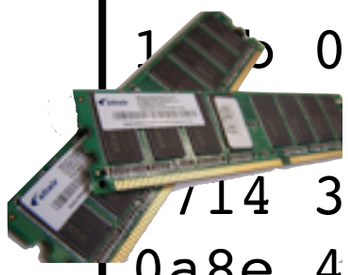
```
w:t></w:r><w:hyperlink r:id=''rId5'' w:history=''1''><w:r w:rsidRPr=
''004B377A''><w:rPr><w:rStyle w:val=''Hyperlink''/></w:rPr><w:t>user
@company.com</w:t></w:r></w:hyperlink><w:r><w:t
```

Word's PDF streams store email addresses with compression and in small chunks.

```
%PDF-1.3
%\304\345\362\345\353\247\363\240\320\304\306
4 0 obj
<< /Length 5 0 R /Filter /FlateDecode >>
stream
x^A\225\222\313n\2030^PE\367\376\212\2734\213:\266^C^FvU\252n
\272\251''Y\352\242\352\242BAi^U\240\201\246\217\277\257\237
\224''\224\250^B\311^^{4>\367\316^\\261\305^QB\332?+\344\252
@\277\303^CZ\254n^F\201j^@w\337P\231<\316d\352c\273)9r^\260R
\241j\260\321$\363\231a\321^MVZ^K\306!\240k<\202\336'\2702^U
@\333]bK\201\342=l>\343U^W\216^H\3
\240\355[^B^KTBqV\346\251\372e#^[\
\313&@\253\300\3305      q\324o\31
_\202\223Y\311\224JE\200#\316\270\
\274^CR\311\377\2263}\250\235\324^
\303^[@(FK\342\325^W\233v'^N\263\2
^M\305T\333\330P\241\314\320\244\3
^H1\261\261I;'\222\357\342=j?\243K
^\\336\366^G\212q\250^D
endstream
endobj
```

```
q Q q 12 12 588 768 re W n /Cs1 cs 0 0 0 sc q 0.24 0 0 0.24 90 708.96
cm BT 50 0 0 50 0 0 Tm /TT1.0 1 Tf [ (O) -0.2 (ne) 0.2 ( t) 0.2 (w)
  -0.2 (o t) 0.2 (hre) 0.2 (e) 0.2 ( ) ] TJ ET Q 0 0 1 sc q 0.24 0 0
0.24 160.9746 708.96 cm BT 50 0 0 50 0 0 Tm /TT1.0 1 Tf [ (us) -0.2
  (e) 0.2 (r@) 0.1 (c) 0.2 (om) 0.2 (pa) 0.2 (ny.c) 0.2 (om) ] TJ ET Q
0 0 0 sc q 0.24 0 0 0.24 259.6641 708.96 cm BT 50 0 0 50 0 0 Tm /TT1.0
1 Tf ( ) Tj ET Q q 0.24 0 0 0.24 262.6641 708.96 cm BT 50 0 0 50 0 0
Tm /TT1.0 1 Tf [ (f) -0.5 (our f) -0.5 (i) 0.2 (ve) 0.2 ( s) -0.2 (i)
  0.2 (x.) ] TJ ET Q q 0.24 0 0 0.24 324.3281 708.96 cm BT 50 0 0 50 0
0 Tm /TT1.0 1 Tf ( ) Tj ET Q 0 0 1 sc 161.04 707.28 m 259.68 707.28 l
259.68 707.04 l 161.04 707.04 l h f 0 0 0 sc q 0.24 0 0 0.24 90 695.28
cm BT 50 0 0 50 0 0 Tm /TT1.0 1 Tf ( ) Tj ET Q Q
```

Encoded data may be *in files* or *between files*.



```
e327 962d 6450 3d91 c945 3bed 97a6 a4cd   .'.-dP=..E;.....
1[illegible]b 0800 0000 0000 0203 8b88 8c72 48ce   .............rH.
[illegible]8cc abd4 03d2 0a8e 4ece 287c 1757   .-H.......N.(|.W
[illegible]714 3e00 b455 c1c5 3000 0000 0000 0000   7.>..U..0.......
0a8e 4ece 287c 1757 3714 3e00 a175 10ed   ..N.(|.W7.>..u..
```

Folders.pst ORACLE

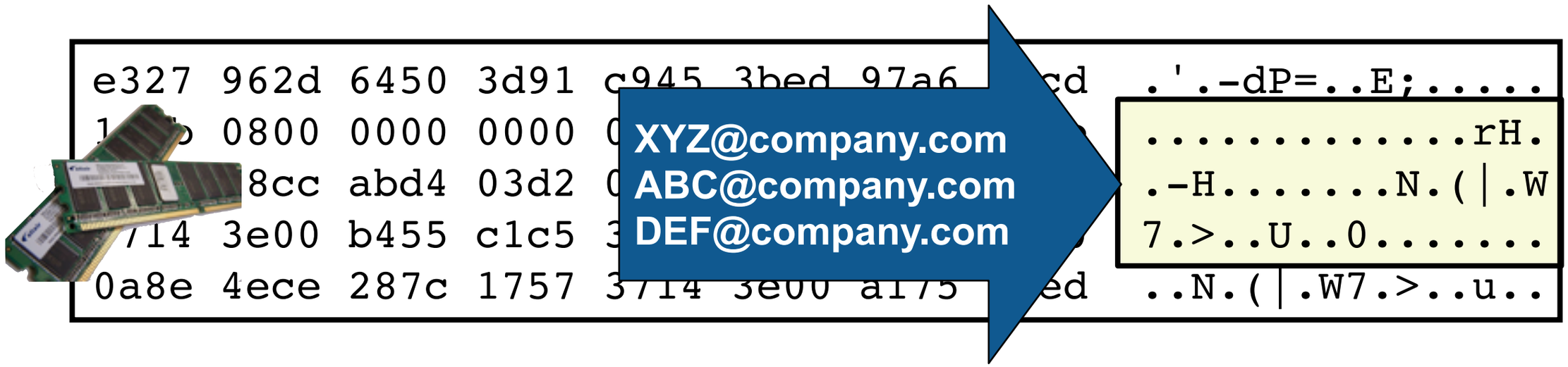
Mother.JPG ORACLE

Presentation.pptx ORACLE

Sequestration.docx ORACLE

```
a097 83a1 ed96 26a6 3c69 3d0f 750a 2399   ......&.<i=.u.#.
a2b5 bea7 692f 5847 a38a dd53 082c add5   ....i/XG...S.,..
5061 b64c 721d 864b 90b6 b55f bb04 735c   Pa.Lr..K..._..s\
9448 6730 5453 df64 813e b603 5795 2242   .Hg0TS.d.>..W."B
e[illegible]8 7454 7322 7cdc b60e 97af 2f64 2728   ..tTs"|...../d'(
[illegible]4bd 2a84 2dfe 50ea 5935 c349 1513   <XYZ@COMPANY.COM
[illegible]e92c a3f8 6e46 0530 8a88 c7a2 5d2b   ...,..nF.0....]+
d89d 77cc fe1e f637 f3f3 d0af 1b47 c09b   ..w....7.....G..
```

Outside In won't extract text from non-file ("bulk") data.



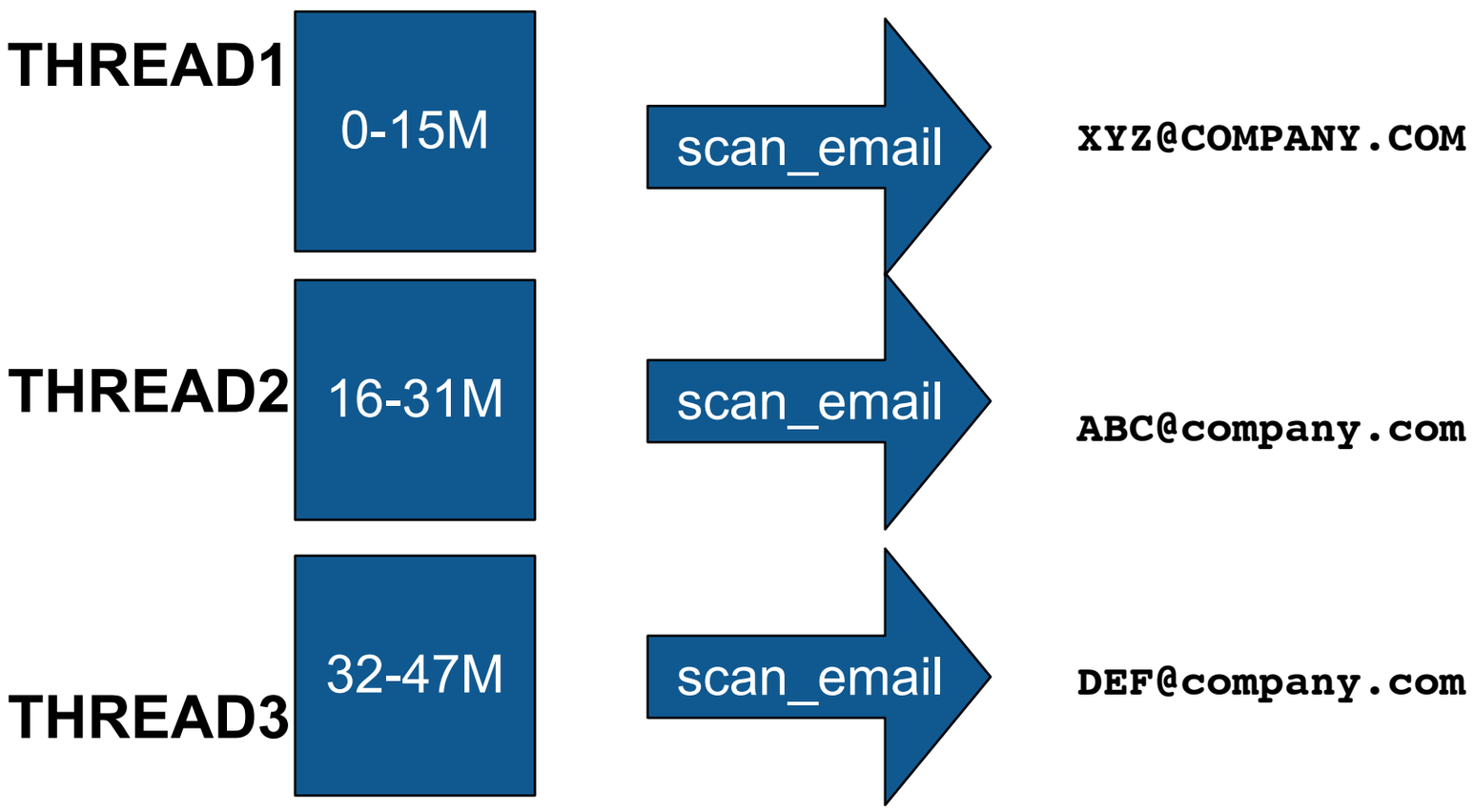
Outside In won't recognize the file type.

- No way to tell Outside In what to process.
- The entire file may not be present.

Examples:

- Compressed — zlib (gzip, ZIP), RAR, Windows Hibernation (Microsoft Xpress)
- Encoded — BASE64
- Obfuscated — ROT13, XOR(255)

bulk_extractor splits the disk into 16M “pages” (blocks) and processes each page independently.

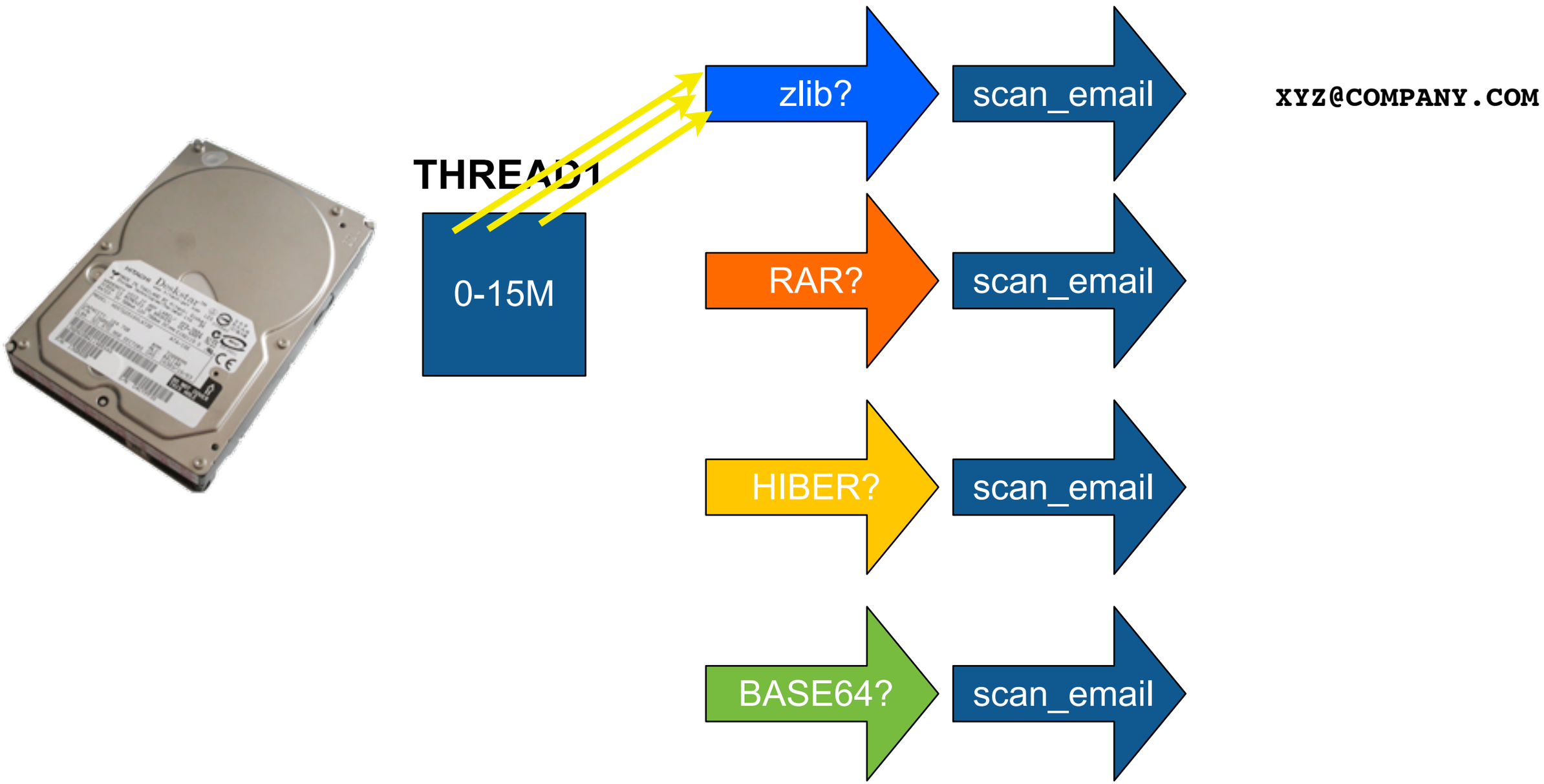


This finds obvious email addresses in bulk data:

```
a097 83a1 ed96 26a6 3c69 3d0f 750a 2399  ......&.<i=.u.#.
a2b5 bea7 692f 5847 a38a dd53 082c add5  ....i/XG...S.,..
5061 b64c 721d 864b 90b6 b55f bb04 735c  Pa.Lr..K..._..s\
9448 6730 5453 df64 813e b603 5795 2242  .Hg0TS.d.>..W."B
e9c8 7454 7322 7cdc b60e 97af 2f64 2728  ..tTs"|...../d'(
3cfb 84bd 2a84 2dfe 50ea 5935 c349 1513  <XYZ@COMPANY.COM
a9e9 e92c a3f8 6e46 0530 8a88 c7a2 5d2b  ...,..nF.0....]+
d89d 77cc fe1e f637 f3f3 d0af 1b47 c09b  ..w....7.....G..
```

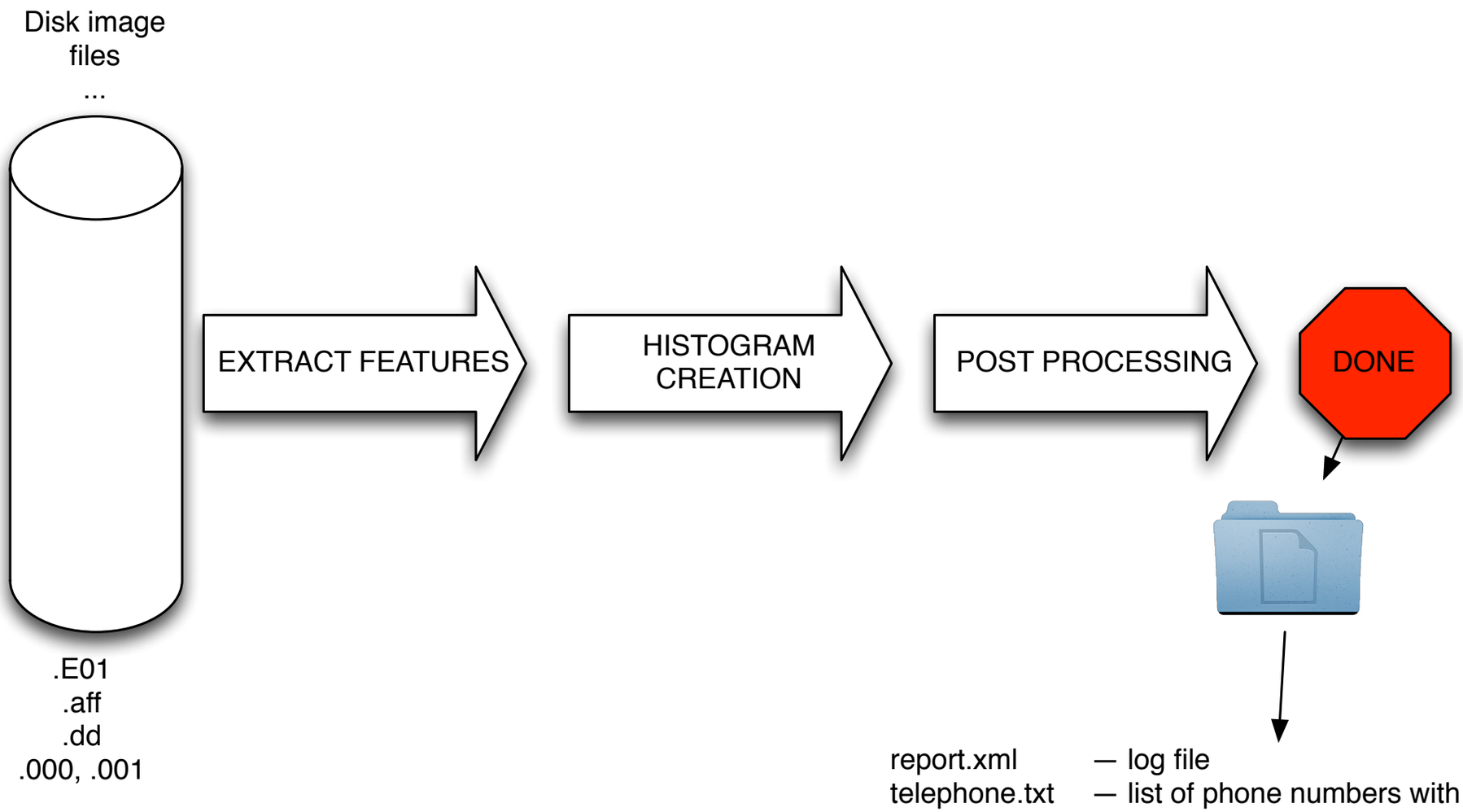
bulk_extractor examines every byte to see if it is the beginning of an “encoded” region.

Once the region is found, it’s decoded, then processed.



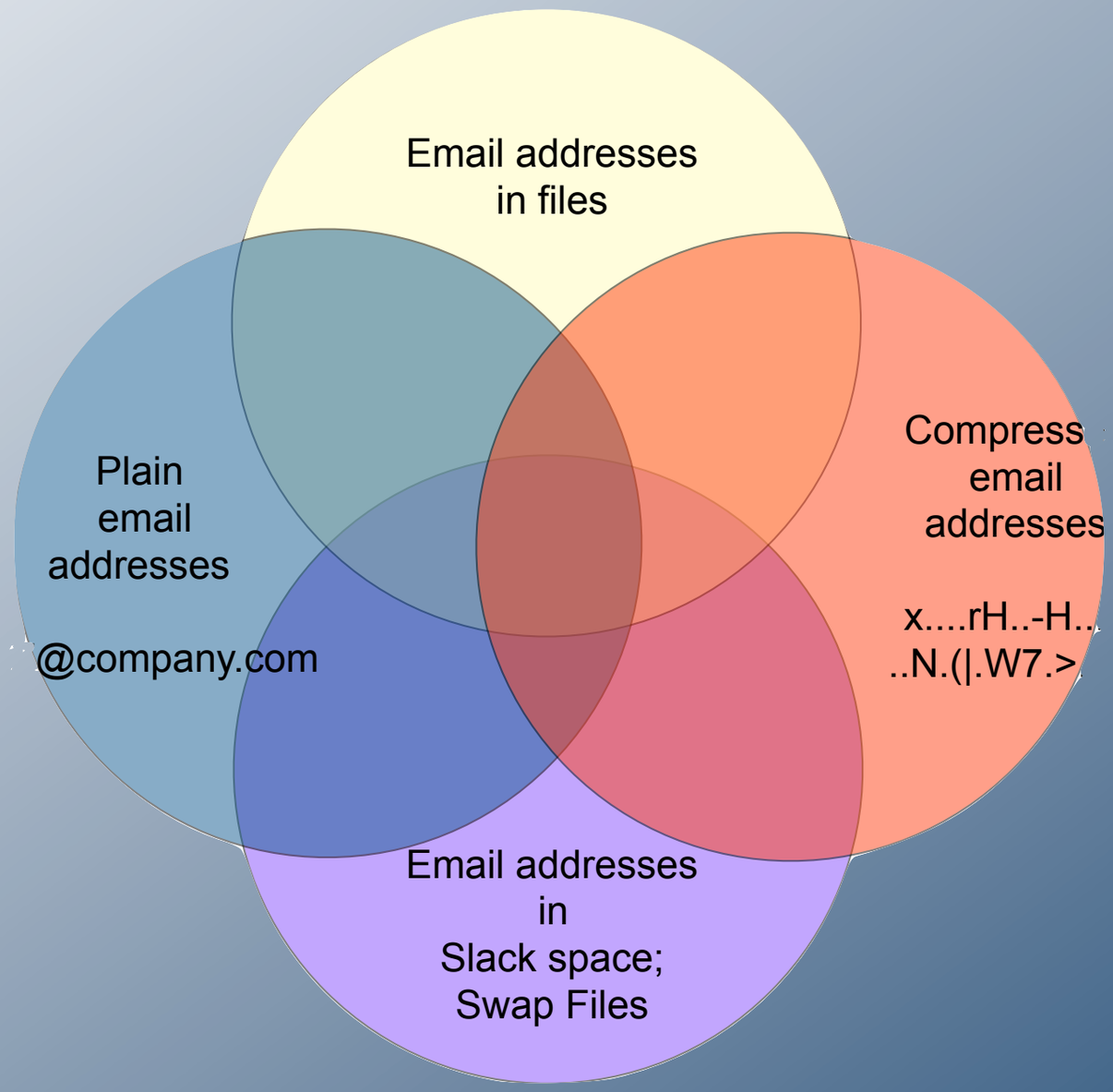
This “optimistic” approach also recovers data from file fragments.

bulk_extractor has three phases of operation: Feature extraction; histogram creation; post processing



Output is a *directory* containing:

- feature files; histograms; carved objects
- Mostly in UTF-8; some XML
- Can be bundled into a ZIP file and processed with bulk_extractor_reader.py



What is the need for optimistic decoding?

Email addresses can be in files

Files

- Documents
- Address book
- Email messages

ABC@company.com
DEF@company.com

Browser Cache:

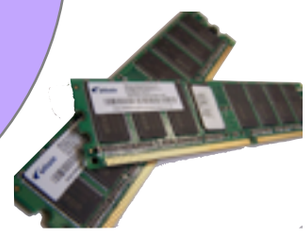
- Web mail
- Facebook Data

Email addresses can be in non-file disk sectors

ABC@company.com
DEF@company.com

XYZ@company.com

Swap Files
Hibernation Files
File fragments



Some may be in *both* files and in non-files.
(A file that's read into RAM before the system hibernates.)

ABC@company.com
DEF@company.com

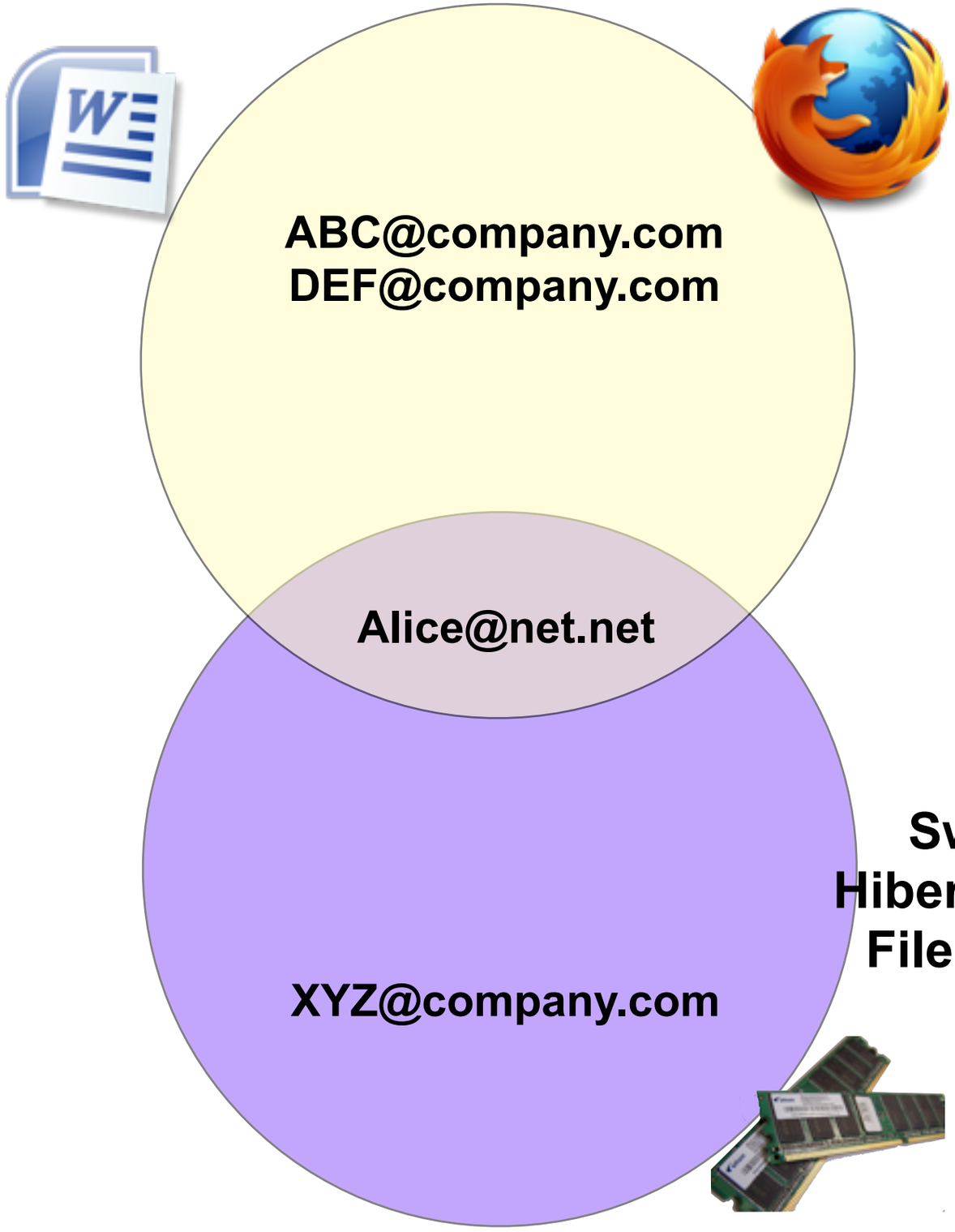
Alice@net.net

Alice@net.net

XYZ@company.com

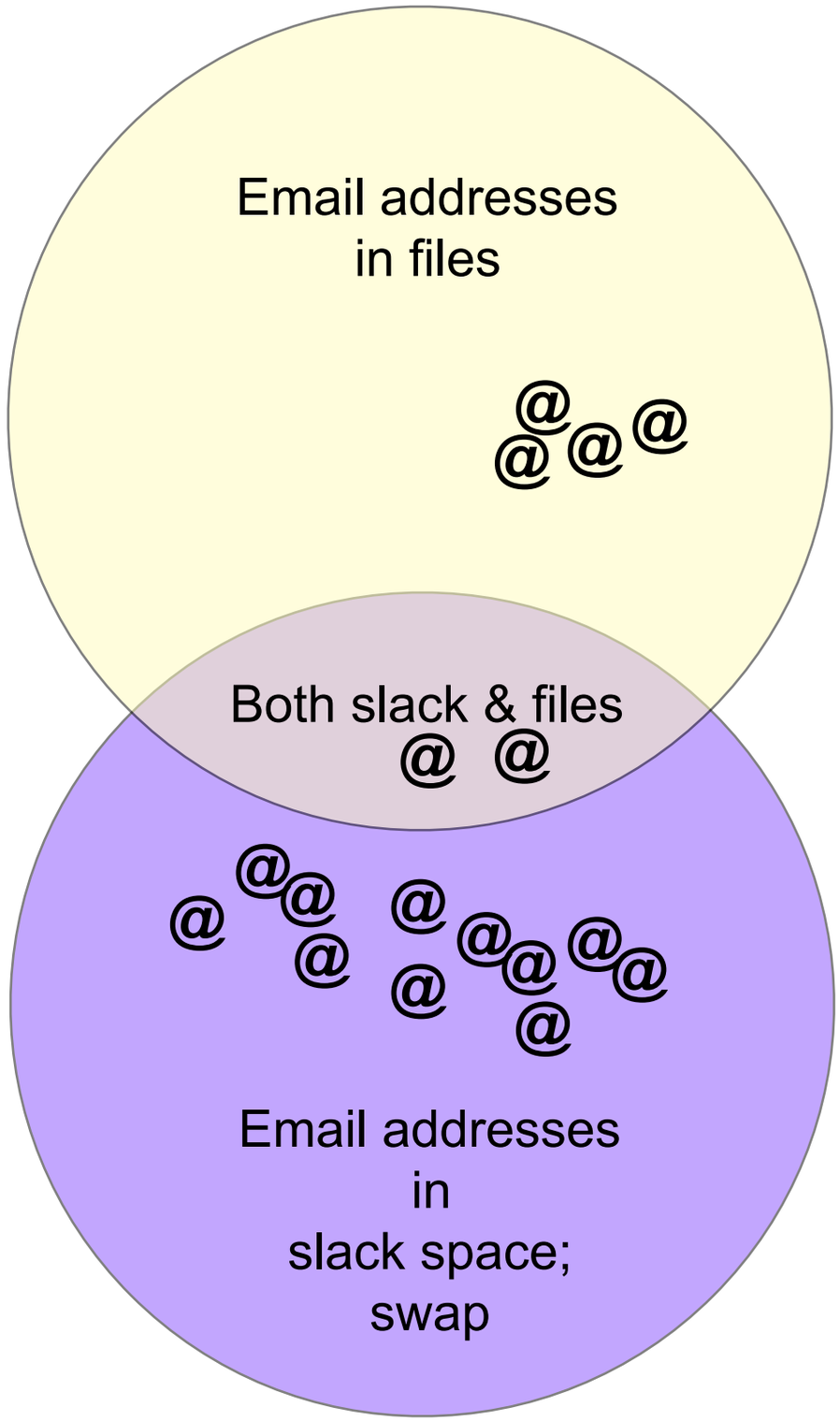
Swap Files
Hibernation Files
File fragments

We can use a Venn Diagram to represent email addresses on the media.

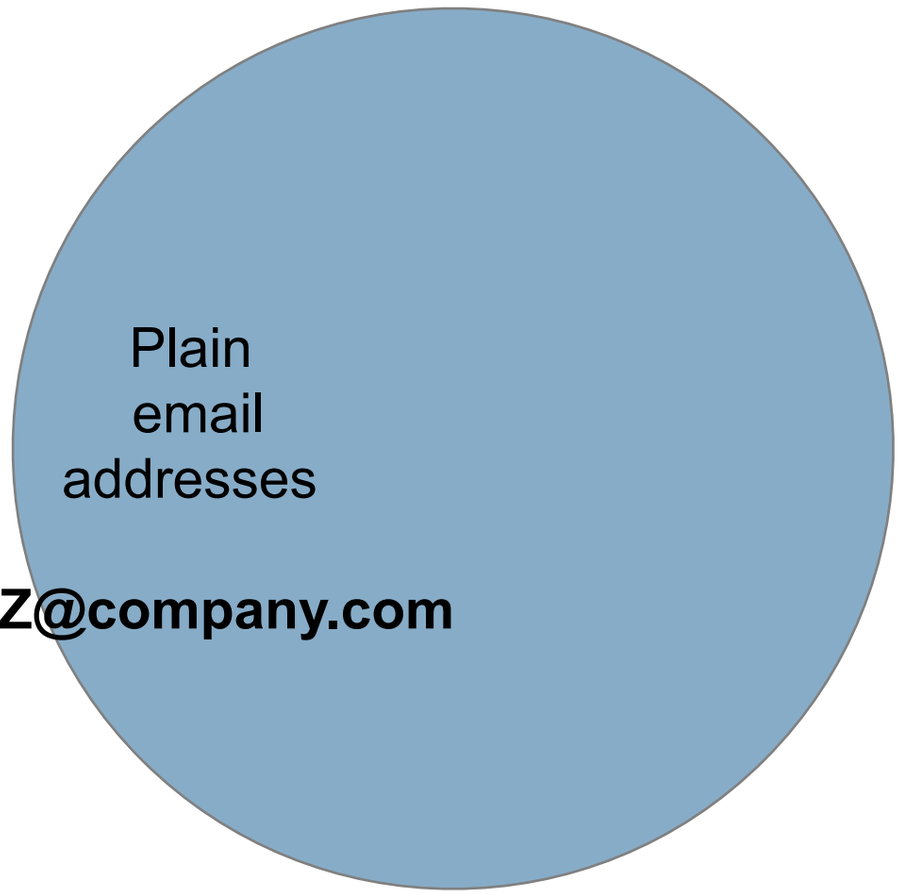


Swap Files
Hibernation Files
File fragments

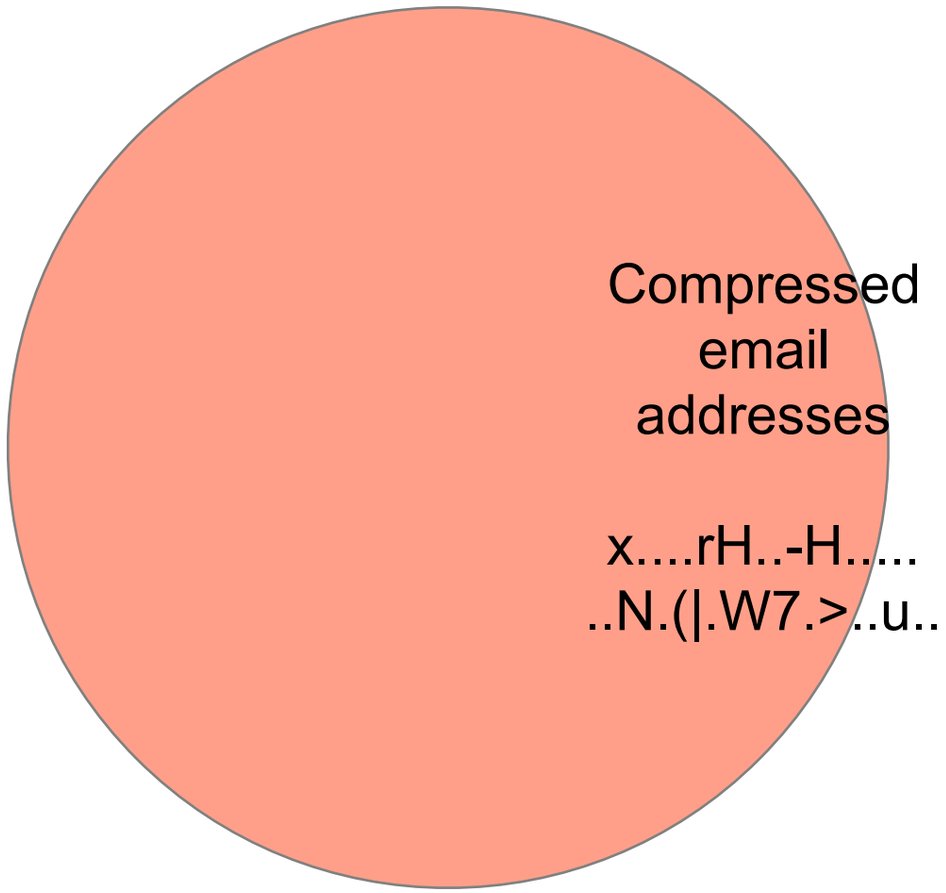
The number of email addresses in each region depends on the media.



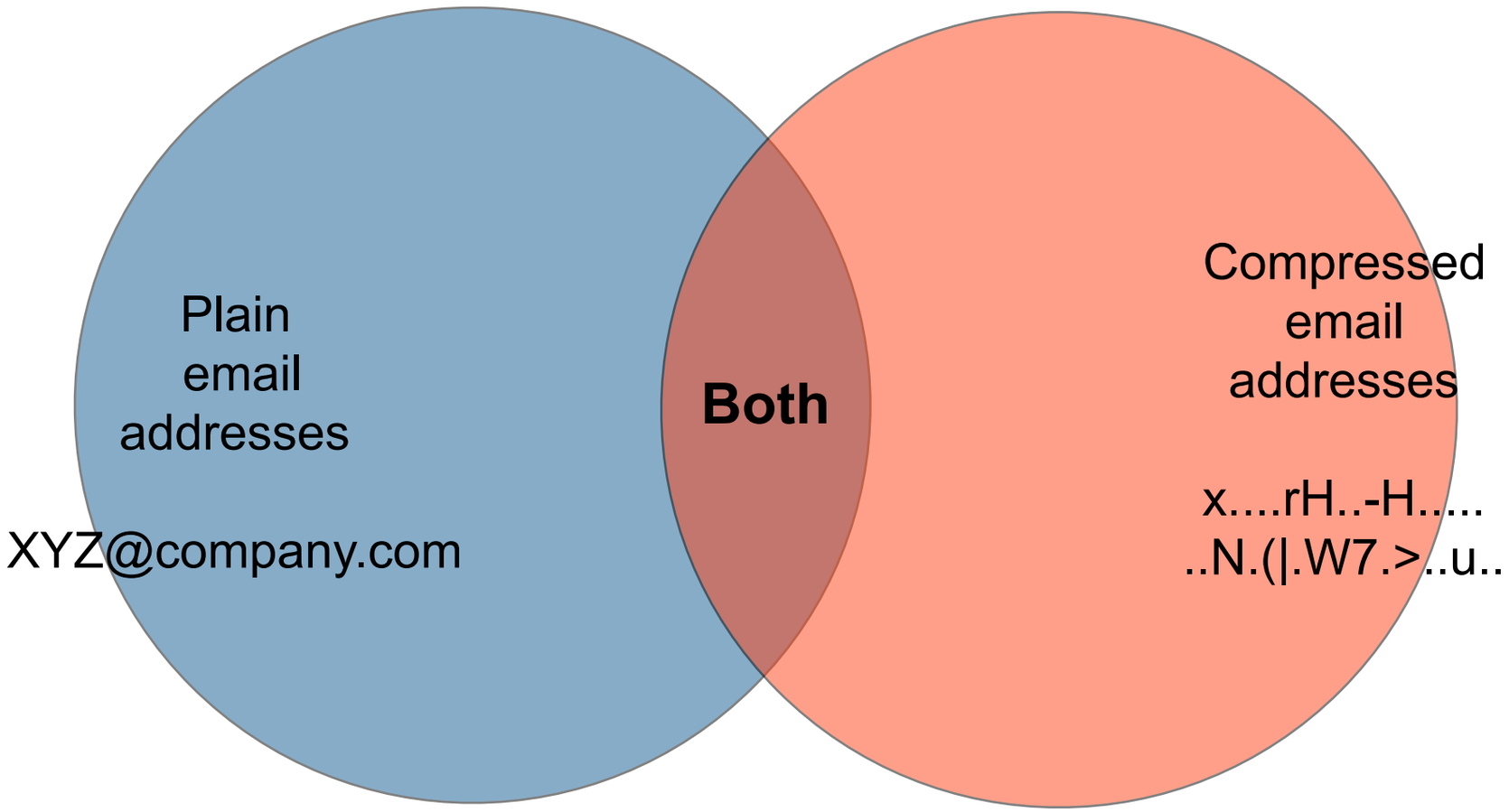
Email addresses can be plain text.
“XYZ@company.com”



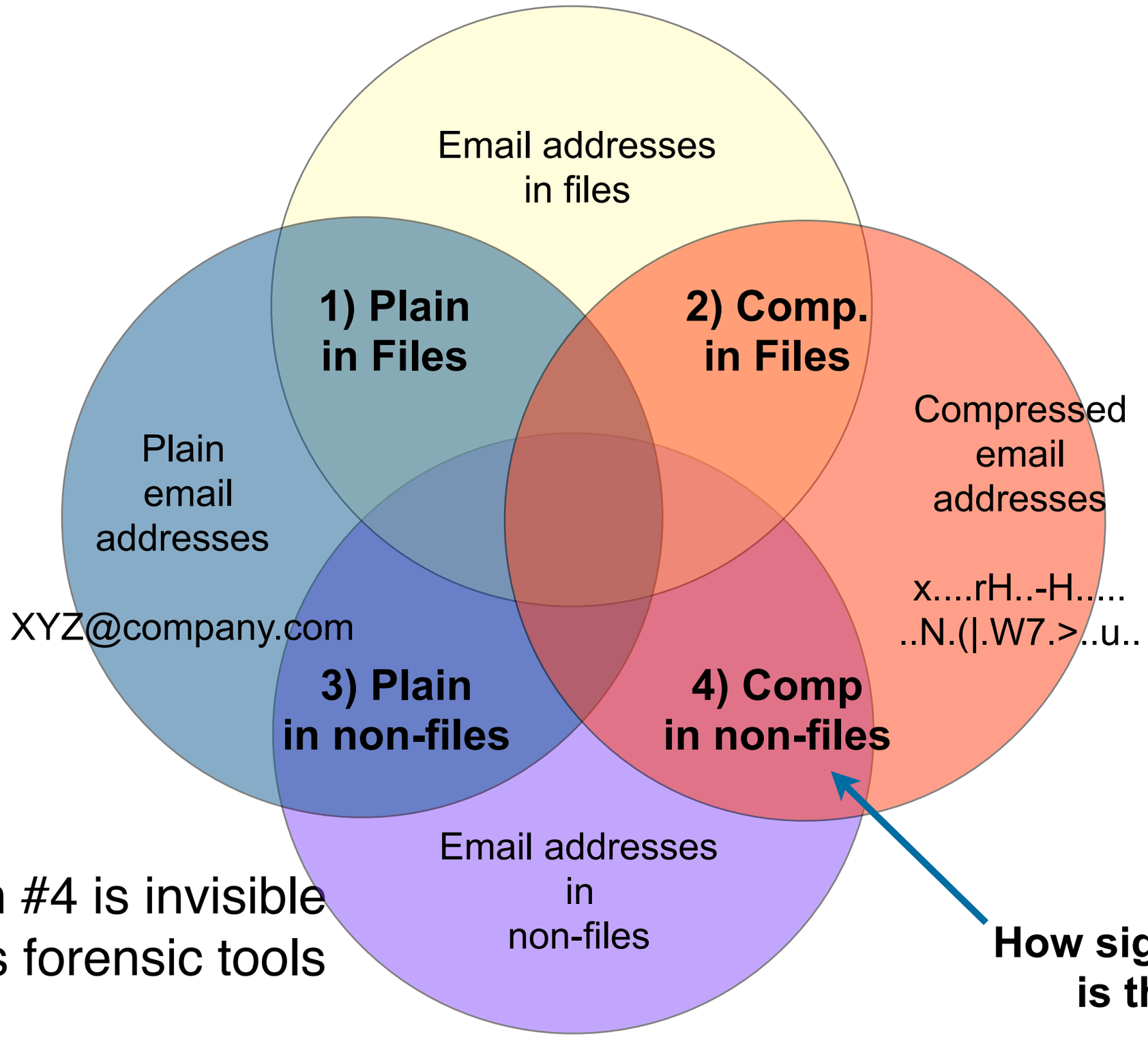
Email addresses can be compressed or encoded. “x....rH..-H.....N.(I.W7.>..u..”



Each email address can be present plain, compressed, or both.



There are four different conditions for an email address on the media.

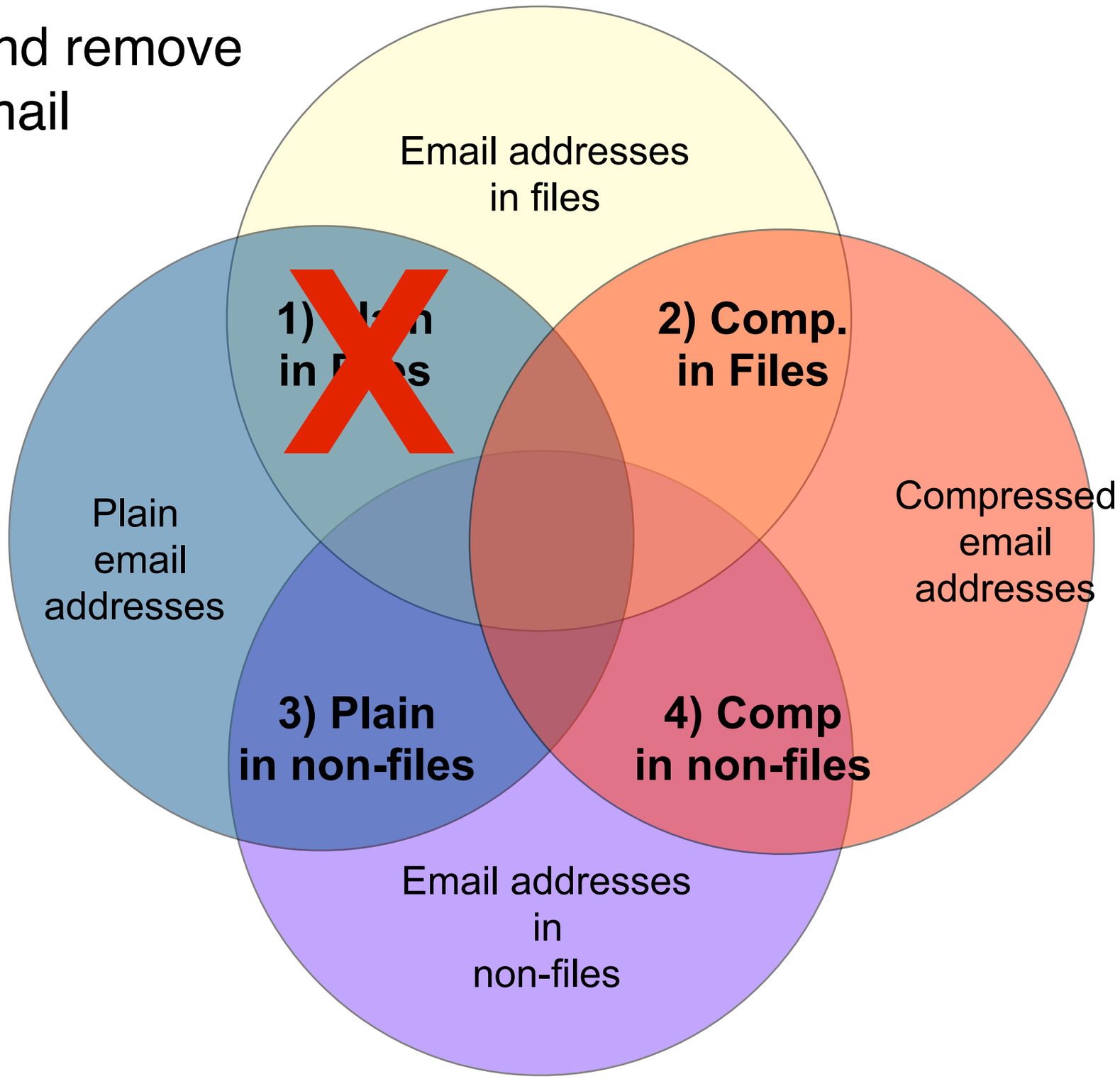


Condition #4 is invisible to today's forensic tools

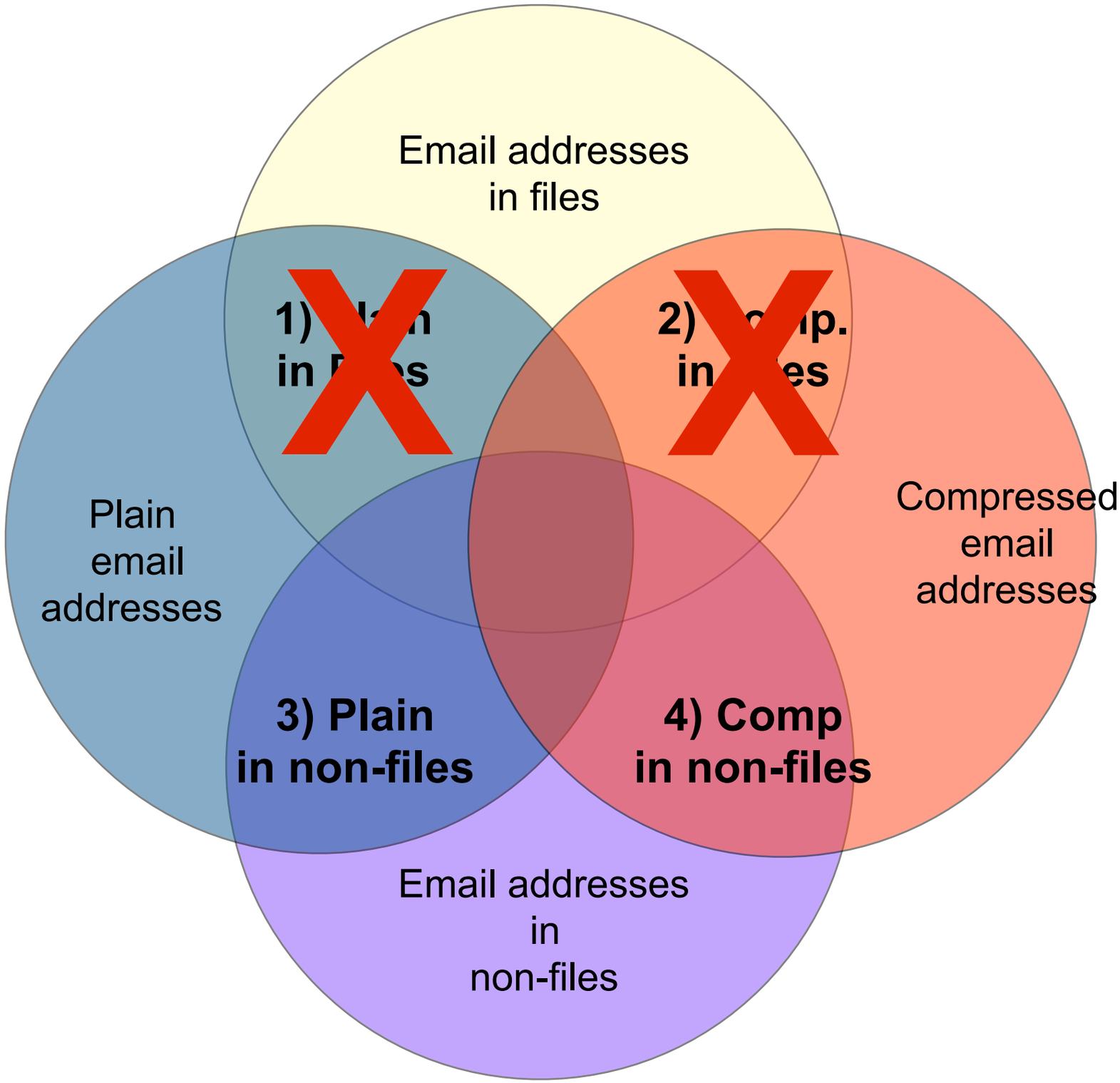
How significant is this?

We devised an experiment to determine the size of condition #4 for a specific drive.

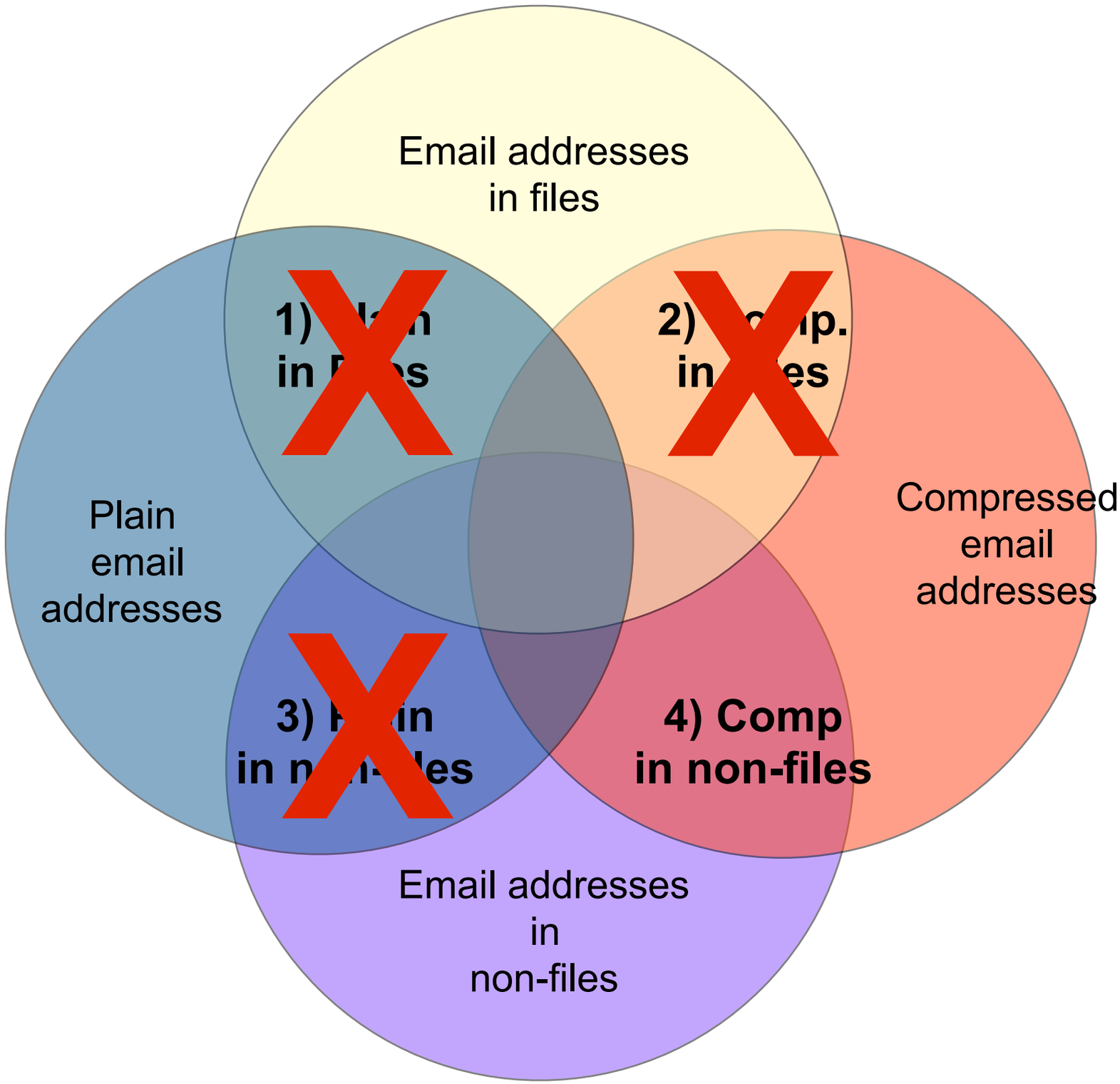
First, find and remove the plain email addresses in files.



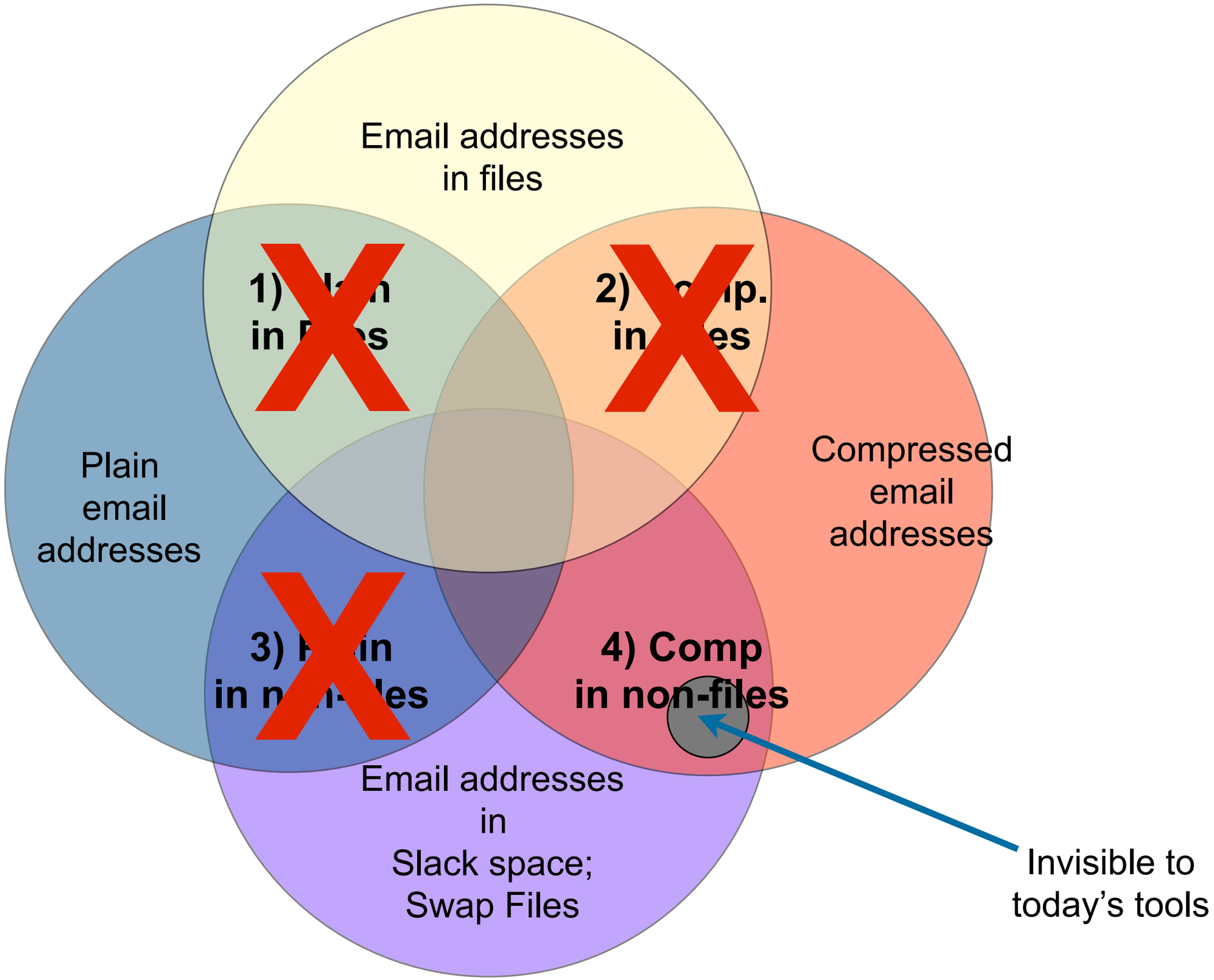
...Remove the addresses compressed and in files....



...Remove email addresses that are not compressed.



...those that remain are the “invisible” email addresses.



We use the Real Data Corpus to determine the prevalence of encoded data in NF space.

The Real Data Corpus (70TB)

- Disks, camera cards, & cell phones purchased on the “secondary market” (used).
- Most contain data from previous users.
- Mostly acquire outside the US:
  - —*Canada, China, England, Germany, France, India, Israel, Japan, Pakistan, Palestine, etc.*
- Thousands of devices (HDs, CDs, DVDs, flash, etc.)
  - —*Garfinkel, Farrell, Roussev and Dinolt, Bringing Science to Digital Forensics with Standardized Forensic Corpora, DFRWS 2009 http://digitalcorpora.org/*

Our answer is qualitative, not quantitate.

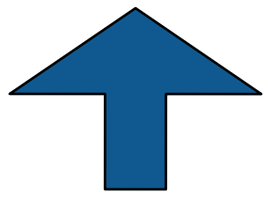
- RDC is not a “Random Sample” of the world’s drive.
- We gain insight into the size of the problem.
- The findings are not representative of any specific case.

bulk_extractor's output indicates what decoding was necessary to extract the feature.

```
# UTF-8 Byte Order Marker; see http://unicode.org/faq/utf_bom.html
#
@
...
392175418    WindowsXP@gn.microsoft.com    Name=WindowsXP@gn.microsoft.com\015\012
...
3772517888-GZIP-28322  user@company.com  onterey-<nobr>user@company.com</nobr>
...
```

Offset

Feature



Context

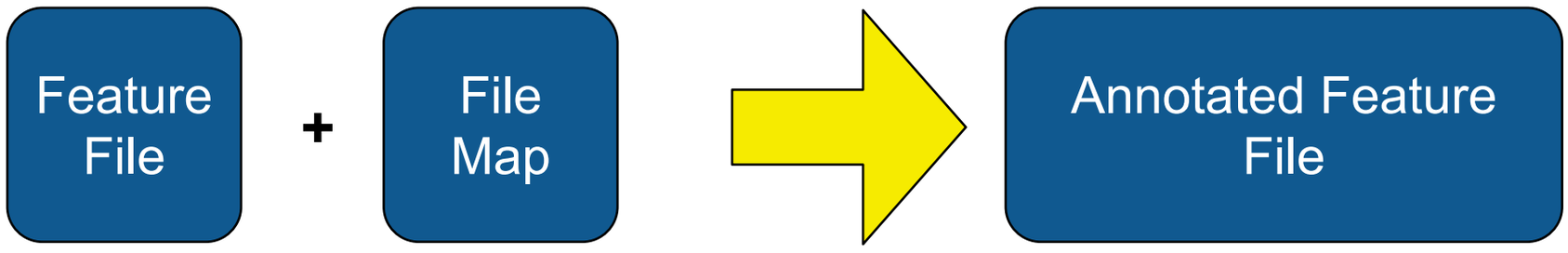
Plain text features have numeric offsets:

```
392175418
```

Compressed features will indicate the algorithm:

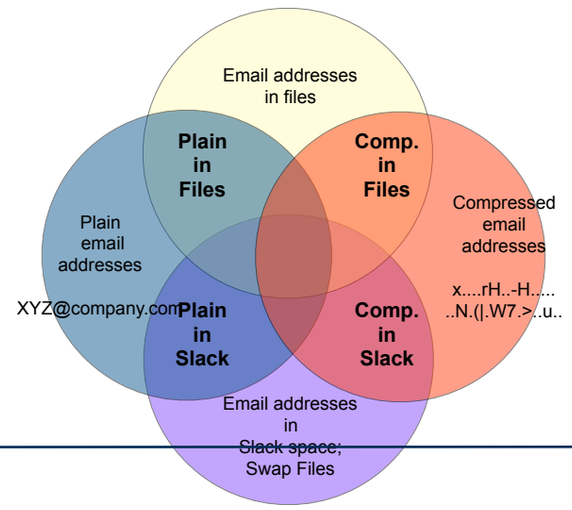
```
3772517888-GZIP-28322
```

The post-processing tool identify_files.py identifies the "file" (if any) from which the feature came.




```
Offset:  392175418
Feature: WindowsXP@gn.microsoft.com
Context:  \012[User]\015\012Name=WindowsXP@gn.microsoft.com
          \015\012Password=B@ji0
Filename:WINDOWS/system32/oobe/migx25a.dun
MD5:     2b00042f7481c7b056c4b410d28f33cf
```

For each feature, we can determine if category #1, #2, #3 and #4!



bulk_extractor 1.5 recognizes a wide variety of features and encoding types:

Feature types:

- Domain Names; Email addresses; URLs, CCNs
- Search terms; Facebook IDs; JSON data
- KML files; EXIF data
- VCARDs
- word search output
- PCAP files; Ethernet Addresses; TCP/IP Connections; etc.
- ELF & PE headers; Windows Prefetch files

```
-rw-r--r--@ 1 simsong  staff       476 Jul  7 23:50 aes_keys.txt
-rw-r--r--@ 1 simsong  staff         0 Jul  7 23:48 alerts.txt
-rw-r--r--@ 1 simsong  staff      2743 Jul  7 23:59 ccn.txt
-rw-r--r--@ 1 simsong  staff       454 Jul  8 00:03 ccn_histogram.txt
-rw-r--r--@ 1 simsong  staff         0 Jul  7 23:48 ccn_track2.txt
-rw-r--r--@ 1 simsong  staff         0 Jul  8 00:03 ccn_track2_histogram.txt
-rw-r--r--@ 1 simsong  staff  23369167 Jul  8 00:03 domain.txt
-rw-r--r--@ 1 simsong  staff    185266 Jul  8 00:03 domain_histogram.txt
-rw-r--r--@ 1 simsong  staff         0 Jul  7 23:48 elf.txt
-rw-r--r--@ 1 simsong  staff   1719842 Jul  8 00:03 email.txt
-rw-r--r--@ 1 simsong  staff     35073 Jul  8 00:03 email_histogram.txt
-rw-r--r--@ 1 simsong  staff     23961 Jul  8 00:00 ether.txt
-rw-r--r--@ 1 simsong  staff       337 Jul  8 00:03 ether_histogram.txt
-rw-r--r--@ 1 simsong  staff  11188830 Jul  8 00:03 exif.txt
-rw-r--r--@ 1 simsong  staff         0 Jul  7 23:48 find.txt
-rw-r--r--@ 1 simsong  staff      1112 Jul  8 00:01 gps.txt
-rw-r--r--@ 1 simsong  staff         0 Jul  7 23:48 hex.txt
-rw-r--r--@ 1 simsong  staff     95835 Jul  8 00:03 ip.txt
-rw-r--r--@ 1 simsong  staff     11603 Jul  8 00:03 ip_histogram.txt
-rw-r--r--@ 1 simsong  staff   2025702 Jul  8 00:03 json.txt
-rw-r--r--@ 1 simsong  staff         0 Jul  7 23:48 kml.txt
-rw-r--r--@ 1 simsong  staff    194991 Jul  8 00:03 packets.pcap
-rw-r--r--@ 1 simsong  staff     21343 Jul  8 00:03 report.xml
-rw-r--r--@ 1 simsong  staff   3782598 Jul  8 00:03 rfc822.txt
-rw-r--r--@ 1 simsong  staff    213746 Jul  8 00:03 tcp.txt
-rw-r--r--@ 1 simsong  staff     61255 Jul  8 00:03 tcp_histogram.txt
-rw-r--r--@ 1 simsong  staff     59469 Jul  8 00:03 telephone.txt
-rw-r--r--@ 1 simsong  staff      6612 Jul  8 00:03 telephone_histogram.txt
-rw-r--r--@ 1 simsong  staff  67205326 Jul  8 00:03 url.txt
-rw-r--r--@ 1 simsong  staff         0 Jul  8 00:03 url_facebook-id.txt
-rw-r--r--@ 1 simsong  staff   5706665 Jul  8 00:03 url_histogram.txt
-rw-r--r--@ 1 simsong  staff         0 Jul  8 00:03 url_microsoft-live.txt
-rw-r--r--@ 1 simsong  staff      8504 Jul  8 00:03 url_searches.txt
-rw-r--r--@ 1 simsong  staff    151673 Jul  8 00:03 url_services.txt
-rw-r--r--@ 1 simsong  staff         0 Jul  7 23:48 vcard.txt
-rw-r--r--@ 1 simsong  staff  18549729 Jul  8 00:03 windirs.txt
-rw-r--r--@ 1 simsong  staff  29051041 Jul  8 00:03 winpe.txt
-rw-r--r--@ 1 simsong  staff   1984759 Jul  8 00:03 winprefetch.txt
-rw-r--r--@ 1 simsong  staff  34128889 Jul  8 00:03 zip.txt
```

Encoding Types:

- ZIP; GZIP; RAR
- BASE16, BASE64
- Windows Hibernation

Some drives have a lot of compressed data

This drive contains a GZIP stream in a Windows Hibernation File.

```
...
…6464-HIBER-49691-GZIP-1526   groups-noreply@linkedin.com    3d\134"groups-noreply@linkedin.com
…6464-HIBER-49691-GZIP-2018   m*****************@gmail.com   3d\134"m*****************@gmail.co
…6464-HIBER-49691-GZIP-2128   sur*******1@gmail.com          3d\134"sur*******1@gmail.com\134"\
…6464-HIBER-49691-GZIP-2625   *******.consultancy@gmail.com 3d\134"*******.consultancy@gmail.c
…6464-HIBER-49691-GZIP-2736   sur*******1@gmail.com          3d\134"sur*******1@gmail.com\134"\
…6464-HIBER-49691-GZIP-3186   san****@***********.com        \134" "san****@***********.com\134"\134u
…6464-HIBER-49691-GZIP-3685   Careers@******bank.com         3d\134"Careers@******bank.com\134"
…6464-HIBER-49691-GZIP-4124   par****@team******.com         3d\134"par****@team******.com\134"
…6464-HIBER-49691-GZIP-4149   u003epar****@team******.com    \134u003epar****@team******.com\13
…6464-HIBER-49691-GZIP-4607   d****.*****@gmail.com          3d\134"d****.*****@gmail.com\134"\
…6464-HIBER-49691-GZIP-4631   u003ed****.*****@gmail.com     \134u003ed****.*****@gmail.com\134
…6464-HIBER-49691-GZIP-5114   raj******@bsnl.in              3d\134"raj******@bsnl.in\134"\134u
…6464-HIBER-49691-GZIP-5558   kiran.***@****technology.com   3d\134"kiran.***@****technology.co
…6464-HIBER-49691-GZIP-5671   sur*******1@gmail.com          3d\134"sur*******1@gmail.com\134"\
...
```

- JSON object downloaded from Facebook by compressed HTTP
- In RAM, written to HIBER on disk when the system went into sleep.

We ran bulk_extractor and identify_filenames.py on drive IN10-0138 and examined the email encodings:

Emails seen	count	1) Plain in Files	2) Comp. in Files	3) Plain in non-files	4) Comp in non-files
Cleartext		358	--	5341	--
All Comp		--	9	--	135
GZIP	50	13	1	22	14
HIBER	39	6	1	27	5
HIBER-GZIP	23			21	2
PDF	88	1		9	78
ZIP	28	2	5	3	18
ZIP-PDF	18				18

135 out of 5700 email addresses were invisible to existing tools.

Many of these email addresses are significant

Example email addresses (sanitized)

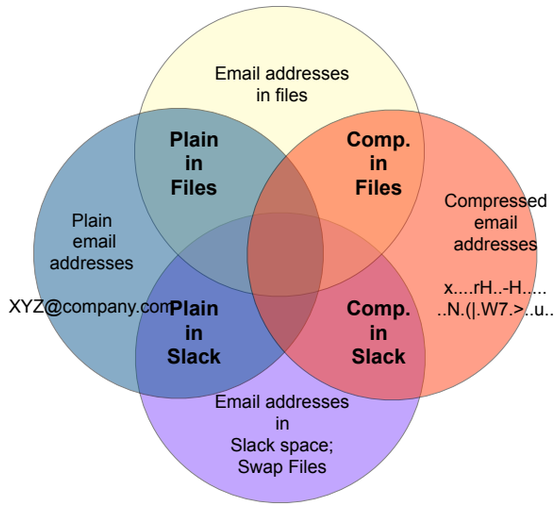
Encoding	Email Address (*Sanitized)	Note
GZIP	****@*****.dk	PII
ZIP	******@desktopsidebar.com	PII
HIBER	ntIV@std.do	false positive
ZIP	****************@digital.com	source code?
ZIP	pcg@goof.com	ECGS Compiler
ZIP	andrew@northwindtraders.com	MS Office Sample
ZIP	ActiveSh@eet.Na	false positive
GZIP	linux-ntfs-dev@lists.sourceforge.net	mailing list

Questions:

- How common are compressed email addresses in unallocated space?
- Is this technique worth the effort?

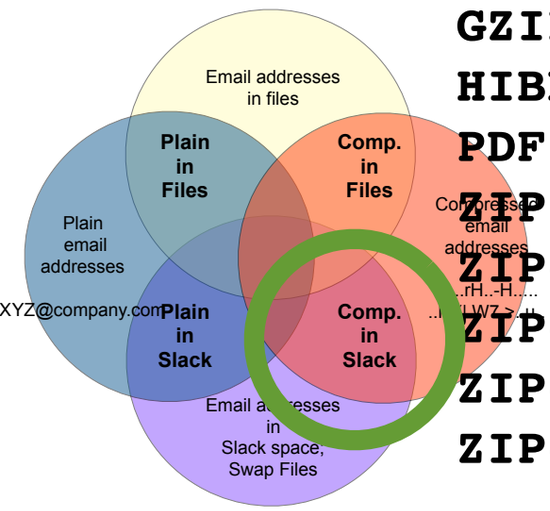
Analysis of 1,646 disk images (Including email addresses present in cleartext)

Coding	Drives	Emails	avg	max	σ
(CLEARTEXT)	949	2,043,168	2,152	178,073	8,890
ZIP	426	86,259	202	59,369	2,887
GZIP	261	79,351	304	9,111	1,035
GZIP-GZIP	17	12,676	745	11,845	2,778
PDF	186	2,569	13	238	30
HIBER	85	1,481	17	220	43
ZIP-ZIP	74	470	6	48	8
ZIP-GZIP	18	307	17	132	31
BASE64	56	250	4	50	7
ZIP-PDF	28	125	4	18	4
ZIP-BASE64-GZIP	2	65	32	38	5
BASE64-GZIP	2	65	32	38	5
GZIP-GZIP-GZIP	4	58	14	38	14
GZIP-ZIP	7	54	7	30	9
GZIP-BASE64	7	44	6	11	3
GZIP-PDF	5	38	7	30	11
GZIP-GZIP-BASE64	2	38	19	30	11
ZIP-BASE64	5	30	6	13	5
GZIP-GZIP-ZIP	1	12	12	12	0
ZIP-ZIP-ZIP	4	10	2	6	2
HIBER-GZIP	1	2	2	2	0
BASE64-GZIP-GZIP	2	2	1	1	0
ZIP-BASE64-GZIP-GZIP	2	2	1	1	0
ZIP-ZIP-PDF	1	1	1	1	0



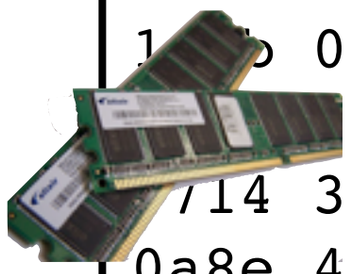
Analysis of 1,646 disk images

Coding	Drives	Emails	avg	max	σ
1) Plain in files	739	81,920	110	4,206	253
2) Comp in files	355	19,711	55	5,454	388
3) Plain in non-files	860	1,956,059	2,274	178,073	9,248
4) Comp in non-files	474	165,481	349	59,376	2,889
BASE64 Comp	54	219	4	50	7
BASE64-GZIP Comp	2	64	32	37	5
GZIP Comp	234	66,195	282	9,103	981
GZIP-BASE64 Comp	7	44	6	11	3
GZIP-GZIP Comp	15	12,663	844	11,845	2,944
GZIP-GZIP-BASE64 Comp	2	38	19	30	11
GZIP-GZIP-GZIP Comp	4	58	14	38	14
GZIP-GZIP-ZIP Comp	1	12	12	12	0
GZIP-PDF Comp	5	38	7	30	11
GZIP-ZIP Comp	6	49	8	30	9
HIBER Comp	79	1,433	18	217	44
PDF Comp	162	2,352	14	238	31
ZIP Comp	388	85,252	219	59,369	3,025
ZIP-BASE64 Comp	5	30	6	13	5
ZIP-BASE64-GZIP Comp	2	65	32	38	5
ZIP-GZIP Comp	14	261	18	132	34
ZIP-PDF Comp	26	115	4	18	4



- Conclusion: Lots of email addresses are being missed.

Some drives have more than TEN THOUSAND email addresses that are compressed and not in a file.



```
e327 962d 6450 3d91 c945 3bed 97a6 [illegible]cd   .'.-dP=..E;.....
[illegible]0800 0000 0000 0[illegible]   .............rH.
[illegible]8cc abd4 03d2 0[illegible]   .-H.......N.(|.W
[illegible]714 3e00 b455 c1c5 3[illegible]   7.>..U..0.......
0a8e 4ece 287c 1757 3714 3e00 a175 [illegible]ed   ..N.(|.W7.>..u..
```

XYZ@company.com
ABC@company.com
DEF@company.com

Folders.pst

Mother.JPG

Presentation.pptx

Sequestration.docx

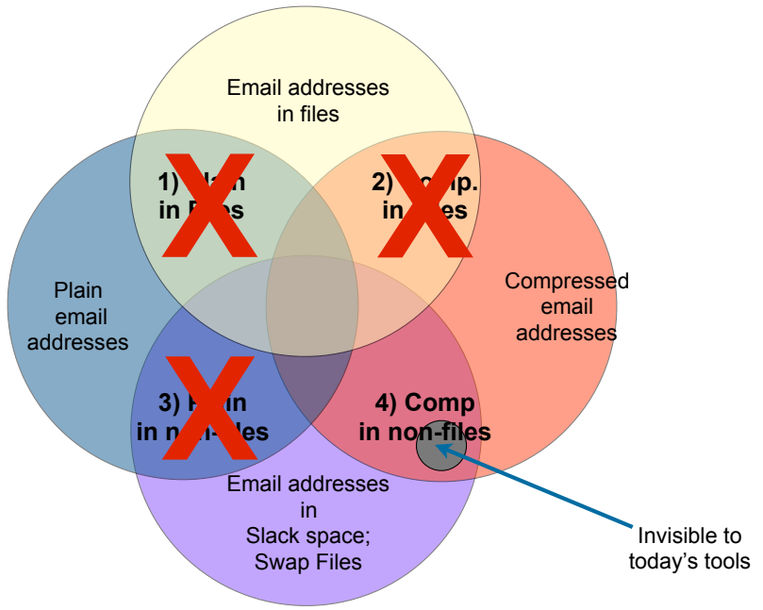
```
a097 83a1 ed96 26a6 3c69 3d0f 750a 2399   ......&.<i=.u.#.
a2b5 bea7 692f 5847 a38a dd53 082c add5   ....i/XG...S.,..
5061 b64c 721d 864b 90b6 b55f bb04 735c   Pa.Lr..K..._..s\
9448 6730 5453 df64 813e b603 5795 2242   .Hg0TS.d.>..W."B
e[illegible]8 7454 7322 7cdc b60e 97af 2f64 2728   ..tTs"|...../d'(
[illegible]4bd 2a84 2dfe 50ea 5935 c349 1513   <XYZ@COMPANY.COM
[illegible]e92c a3f8 6e46 0530 8a88 c7a2 5d2b   ...,..nF.0....]+
d89d 77cc fe1e f637 f3f3 d0af 1b47 c09b   ..w....7.....G..
```

Difference sources produce different encodings.

Encoding	Primary Source	Drives with Encoding in Non-File Space
BASE64	Email attachments SSL Certificates	54
BASE64-GZIP	Source Code	2
GZIP	Web browser cache	234
ZIP	Java libraries	388
ZIP-PDF	Archives of personal documents	26
ZIP-ZIP-ZIP	WinZip Distributions	3

In summary:
Significant encoded data are in non-file space.

Important, relevant data is ignored by today's tools.

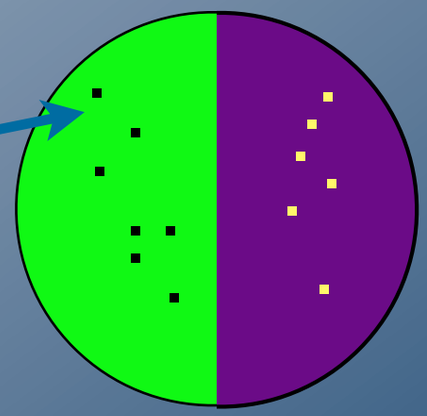


This problem was demonstrated with:

- bulk_extractor, a high-performance stream-based feature extractor
  - *http://digitalcorpora.org/downloads/bulk_extractor (downloads)*
  - *http://www.sciencedirect.com/science/article/pii/S0167404812001472 (paper)*
  - *http://simson.net/clips/academic/2013.COSE.bulk_extractor.pdf*
- Real Data Corpus:
  - *http://digitalcorpora.org/*

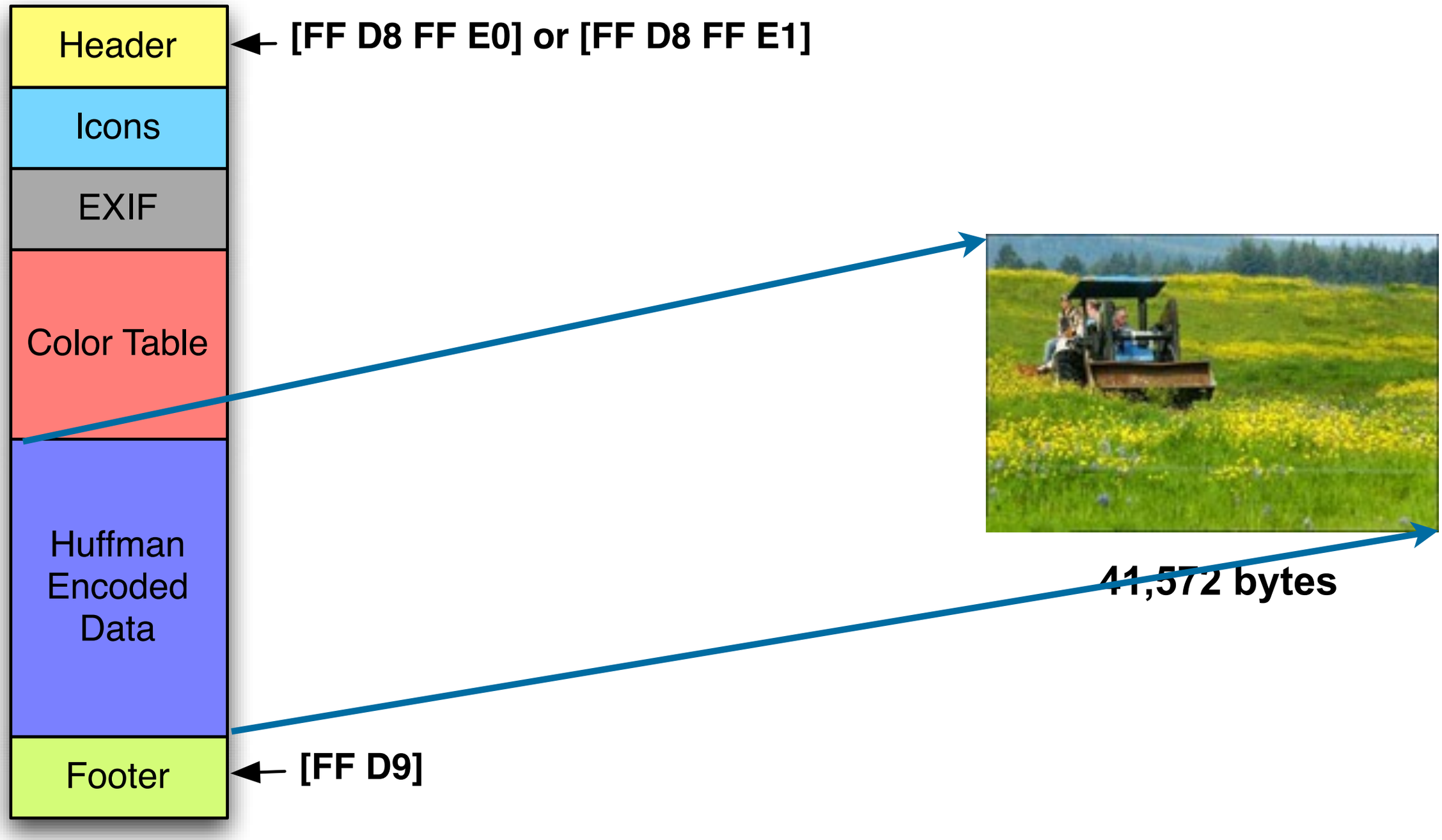
"The Prevalence of Encoding Digital Trace Evidence in Nonfile Space of Computer Media,"
Simson L. Garfinkel,
***Journal of Forensic Sciences*, 2014**

000107.jpg

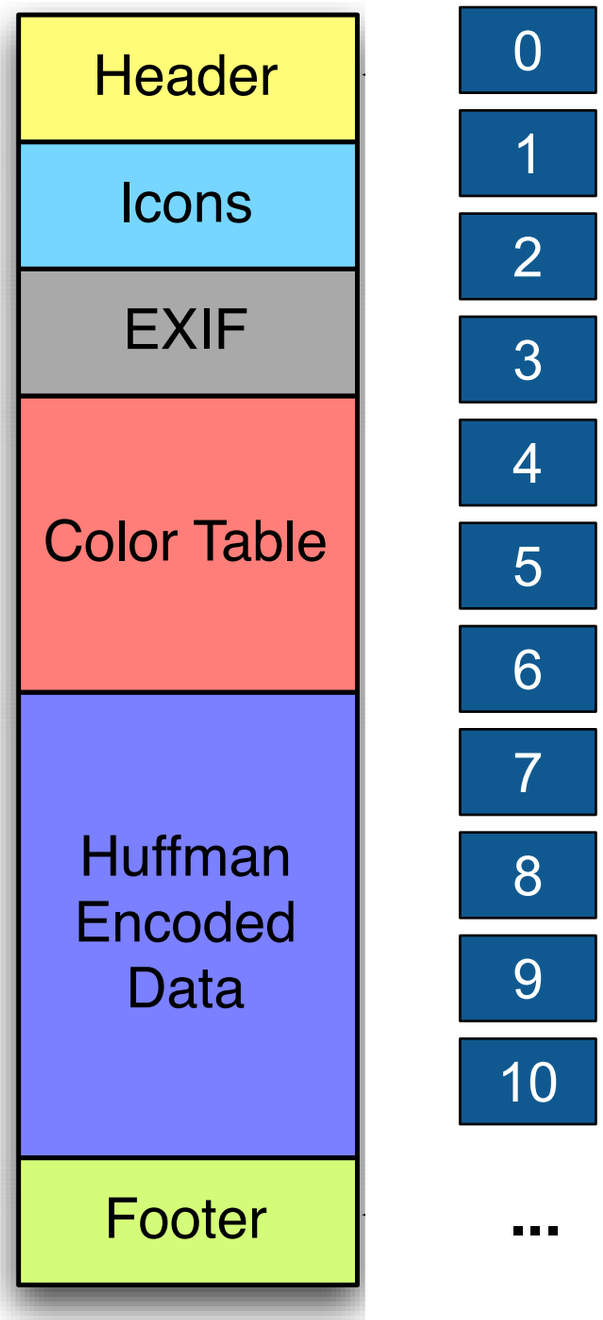


Finding “known content” with sector hashes.

JPEG files have internal structure.
Much of this structure is “high entropy.”



We can view the 41K file as a sequence of 88 512-byte blocks



Block #	Hex Values...
0	ffd8 ffe0 0010 4a46 4946 0001 0201 0048...
1	0c0c 0c0c ffc0 0011 0800 6a00 a003 0122...
2	4fa7 7567 ded2 cac5 8c82 2bf4 9e1c 23f9...
3	fafd 1527 e459 e934 c173 59ad 9234 f09f...
...	...

Each block has a cryptographic hash.

Block #	Byte Range	MD5(block(N))
0	0- 511	**dc0c20abad42d487a74f308c69d18a5a**
1	512-1023	**9e7bc64399ad87ae9c2b545061959778**
2	1024-1535	**6e7f3577b100f9ec7fae18438fd5b047**
3	1536-2047	**4594899684d0565789ae9f364885e303**
4	...	

Question: do these hashes appear in other JPEGs?

- "Distinct" hashes do not.

How do you determine if a block is distinct?

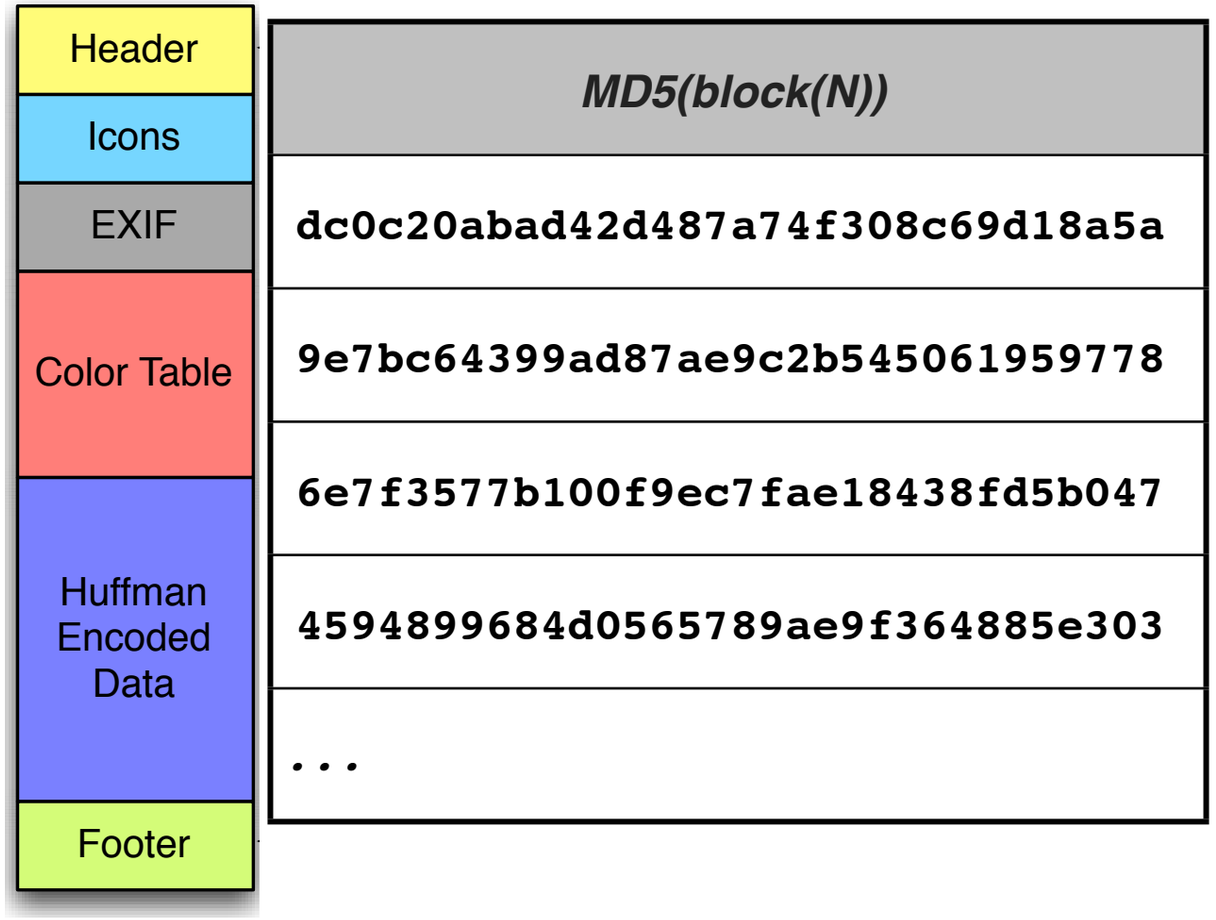
Specific byte sequences in high-entropy data are very rare.

- 512 bytes = 256^{512} =$10^{1,233}$ possible sectors

But metadata might be common:

- Specific headers
- Common color tables
- “all black”

You need to survey
a large samples of JPEGs
to find out which hashes are
common and which are distinct.



We examined sector hashes from ≃4 million files

≃ 1 million in GOVDOCS1 collection

= 109,282 JPEGs (including 000107.jpg)

≃ 3 million samples of Windows malware

Results:

- Most of the block hashes in 000107.jpg do not appear elsewhere in the corpus.
- Some of the block hashes appeared in other JPEGs.
- None of the block hashes appeared in files that were not JPEGs

The beginning of 000107.jpg contains distinct hashes...

hash	location	count
dc0c20abad42d487a74f308c69d18a5a	offset 0-511	1
9e7bc64399ad87ae9c2b545061959778	offset 512-1023	1
6e7f3577b100f9ec7fae18438fd5b047	offset 1024-1535	1
4594899684d0565789ae9f364885e303	offset 1536-2047	1
4d21b27ceec5618f94d7b62ad3861e9a	offset 2048-2559	1
03b6a13453624f649bbf3e9cd83c48ae	offset 2560-3071	1
c996fe19c45bc19961d2301f47cabaa6	offset 3072-3583	1
0691baa904933c9946bbda69c019be5f	offset 3584-4095	1
1bd9960a3560b9420d6331c1f4d95fec	offset 4096-4607	1
52ef8fe0a800c9410bb7a303abe35e64	offset 4608-5119	1
b8d5c7c29da4188a4dcaa09e057d25ca	offset 5120-5631	1
3d7679a976b91c6eb8acd1bfa3414f96	offset 5632-6143	1
8649f180275e0b63253e7ee0e8fa4c1d	offset 6144-6655	1
60ebc8acb8467045e9dcbe207f61a6c2	offset 6656-7167	1
440c1c1318186ac0e42b2977779514a1	offset 7168-7679	1
72686172f8c865231e2b30b2829e3dd9	offset 7680-8191	1
fdff55c618d434416717e5ed45cb407e	offset 8192-8703	1
fcd89d71b5f728ba550a7bc017ea8ff1	offset 8704-9215	1
2d733e47c5500d91cc896f99504e0a38	offset 9216-9727	1
2152fdde0e0a62d2e10b4fecc369e4c6	offset 9728-10239	1
692527fa35782db8592486343 6d45d7f	offset 10240-10751	1
76dbb9b469273d0e0e467a55728b7883	offset 10752-11263	1

The middle of 000107.JPG appears elsewhere...

hash	location	count
9df886fdfa6934cc7dcf10c04be3464a	offset 14848-15359	1
95399e7ecc7ba1b38243069bdd5c263a	offset 15360-15871	1
ef1ffcdc11162ecdfedd2dde644ec8f2	offset 15872-16383	1
7eb35c161e91b215e2a1d20c32f4477e	offset 16384-16895	1
38f9b6f045db235a14b49c3fe7b1cec3	offset 16896-17407	1
edceba3444b5551179c791ee3ec627a5	offset 17408-17919	1
6bc8ed0ce3d49dc238774a2bdeb7eca7	offset 17920-18431	1
5070e4021866a547aa37e5609e401268	offset 18432-18943	14
13d33222848d5b25e26aefb87dbdf294	offset 18944-19455	9198
0dfcde85c648d20aed68068cc7b57c25	offset 19456-19967	9076
756f0bbe70642700aafb2557bf2c5649	offset 19968-20479	9118
c2c29016d3005f7a1df247168d34e673	offset 20480-20991	9237
42ff3d72b2b25f880be21fac46608cc9	offset 20992-21503	9708
b943cd0ea25e354d4ac22b886045650d	offset 21504-22015	9615
a003ec2c4145b0bc871118842b74f385	offset 22016-22527	9564
1168c351f57aad14de135736c06665ea	offset 22528-23039	7
51a50e6148d13111669218dc40940ce5	offset 23040-23551	83
365b122f53075cb76b39ca1366418ff9	offset 23552-24063	83
9ad9660e7c812e2568aaf063a1be7d05	offset 24064-24575	84
67bd01c2878172e2853f0aef341563dc	offset 24576-25087	84
fc3e47d734d658559d1624c8b1cbf2c1	offset 25088-25599	84
cb9aef5b7f32e2a983e67af38ce8ff87	offset 25600-26111	1

Block 37 had 9198 corpus collisions.
The sector is filled with blank lines 100 characters long...

```
13d33222848d5b25e26aefb87dbdf294   offset 18944-19455      9198

$ dd if=000107.jpg skip=18944 count=512 bs=1|xxd
0000000: 2020 2020 2020 2020 2020 2020 2020 2020
0000010: 2020 2020 2020 2020 2020 2020 0a20 2020                .
0000020: 2020 2020 2020 2020 2020 2020 2020 2020
0000030: 2020 2020 2020 2020 2020 2020 2020 2020
0000040: 2020 2020 2020 2020 2020 2020 2020 2020
0000050: 2020 2020 2020 2020 2020 2020 2020 2020
0000060: 2020 2020 2020 2020 2020 2020 2020 2020
0000070: 2020 2020 2020 2020 2020 2020 2020 2020
0000080: 200a 2020 2020 2020 2020 2020 2020 2020    .
0000090: 2020 2020 2020 2020 2020 2020 2020 2020
00000a0: 2020 2020 2020 2020 2020 2020 2020 2020
00000b0: 2020 2020 2020 2020 2020 2020 2020 2020
00000c0: 2020 2020 2020 2020 2020 2020 2020 2020
00000d0: 2020 2020 2020 2020 2020 2020 2020 2020
00000e0: 2020 2020 2020 0a20 2020 2020 2020 2020                .
00000f0: 2020 2020 2020 2020 2020 2020 2020 2020
0000100: 2020 2020 2020 2020 2020 2020 2020 2020
0000110: 2020 2020 2020 2020 2020 2020 2020 2020
0000120: 2020 2020 2020 2020 2020 2020 2020 2020
```

Block 45 had 83 collisions..
It appears to contain EXIF metadata

```
51a50e6148d13111669218dc40940ce5   offset 23040-23551  83
$ dd if=000107.jpg skip=23040 count=512 bs=1|xxd
0000000: 3936 362d 322e 3100 0000 0000 0000 0000  966-2.1.........
0000010: 0000 0000 0000 0000 0000 0000 0000 0000  ................
0000020: 0000 0000 0000 0000 0000 0000 0000 0000  ................
0000030: 0000 0000 0000 0000 0058 595a 2000 0000  .........XYZ ...
0000040: 0000 00f3 5100 0100 0000 0116 cc58 595a  ....Q........XYZ
0000050: 2000 0000 0000 0000 0000 0000 0000 0000   ...............
0000060: 0058 595a 2000 0000 0000 006f a200 0038  .XYZ ......o...8
0000070: f500 0003 9058 595a 2000 0000 0000 0062  .....XYZ ......b
0000080: 9900 00b7 8500 0018 da58 595a 2000 0000  .........XYZ ...
0000090: 0000 0024 a000 000f 8400 00b6 cf64 6573  ...$.........des
00000a0: 6300 0000 0000 0000 1649 4543 2068 7474  c........IEC htt
00000b0: 703a 2f2f 7777 772e 6965 632e 6368 0000  p://www.iec.ch..
00000c0: 0000 0000 0000 0000 0016 4945 4320 6874  ..........IEC ht
00000d0: 7470 3a2f 2f77 7777 2e69 6563 2e63 6800  tp://www.iec.ch.
00000e0: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000f0: 0000 0000 0000 0000 0000 0000 0000 0000  ................
0000100: 0000 0000 0000 0000 0000 0000 0064 6573  .............des
0000110: 6300 0000 0000 0000 2e49 4543 2036 3139  c........IEC 619
0000120: 3636 2d32 2e31 2044 6566 6175 6c74 2052  66-2.1 Default R
0000130: 4742 2063 6f6c 6f75 7220 7370 6163 6520  GB colour space
```

Block 48 had 84 collisions..
It appears to contain part of a JPEG color table...

```
67bd01c2878172e2853f0aef341563dc   offset 24576-25087        84
$ dd if=000107.jpg skip=24576 count=512 bs=1 |xxd
0000000: 7a27 ab27 dc28 0d28 3f28 7128 a228 d429  z'.'.(.(?(q(.(.)
0000010: 0629 3829 6b29 9d29 d02a 022a 352a 682a  .)8)k).).*.*5*h*
0000020: 9b2a cf2b 022b 362b 692b 9d2b d12c 052c  .*.+.+6+i+.+.,.,
0000030: 392c 6e2c a22c d72d 0c2d 412d 762d ab2d  9,n,.,.-.-A-v-.-
0000040: e12e 162e 4c2e 822e b72e ee2f 242f 5a2f  ....L....../$/Z/
0000050: 912f c72f fe30 3530 6c30 a430 db31 1231  ././.0501l0.0.1.1
0000060: 4a31 8231 ba31 f232 2a32 6332 9b32 d433  J1.1.1.2*2c2.2.3
0000070: 0d33 4633 7f33 b833 f134 2b34 6534 9e34  .3F3.3.3.4+4e4.4
0000080: d835 1335 4d35 8735 c235 fd36 3736 7236  .5.5M5.5.5.676r6
0000090: ae36 e937 2437 6037 9c37 d738 1438 5038  .6.7$7`7.7.8.8P8
00000a0: 8c38 c839 0539 4239 7f39 bc39 f93a 363a  .8.9.9B9.9.9.:6:
00000b0: 743a b23a ef3b 2d3b 6b3b aa3b e83c 273c  t:.:.;-;k;.;.<'<
00000c0: 653c a43c e33d 223d 613d a13d e03e 203e  e<.<.="=a=.=.> >
00000d0: 603e a03e e03f 213f 613f a23f e240 2340  `>.>.?!?a?.?.@#@
00000e0: 6440 a640 e741 2941 6a41 ac41 ee42 3042  d@.@.A)AjA.A.B0B
00000f0: 7242 b542 f743 3a43 7d43 c044 0344 4744  rB.B.C:C}C.D.DGD
0000100: 8a44 ce45 1245 5545 9a45 de46 2246 6746  .D.E.EUE.E.F"FgF
0000110: ab46 f047 3547 7b47 c048 0548 4b48 9148  .F.G5G{G.H.HKH.H
0000120: d749 1d49 6349 a949 f04a 374a 7d4a c44b  .I.IcI.I.J7J}J.K
0000130: 0c4b 534b 9a4b e24c 2a4c 724c ba4d 024d  .KSK.K.L*LrL.M.M
```

With blocks of 512 bytes and 4KiB, the vast majority of sectors were distinct.

Table 1. Incidence of singleton, paired, and common sectors in three file corpora.

No. of blocks	Govdocs	OpenMalware 2012	2009 NSRL RDS
Block size: 512 bytes			
Singleton	911.4 M (98.93%)	1,063.1 M (88.69%)	N/A
Pair	7.1 M (.77%)	75.5 M (6.30%)	N/A
Common	2.7 M (.29%)	60.0 M (5.01%)	N/A
Block size: 4 kibibytes			
Singleton	117.2 M (99.46%)	143.8 M (89.51%)	567.0 M (96.00%)
Pair	0.5 M (.44%)	9.3 M (5.79%)	16.4 M (2.79%)
Common	0.1 M (.11%)	7.6 M (4.71%)	7.1 M (1.21%)

Young, Foster, Garfinkel & Fairbanks, IEEE Computer, Dec. 2012

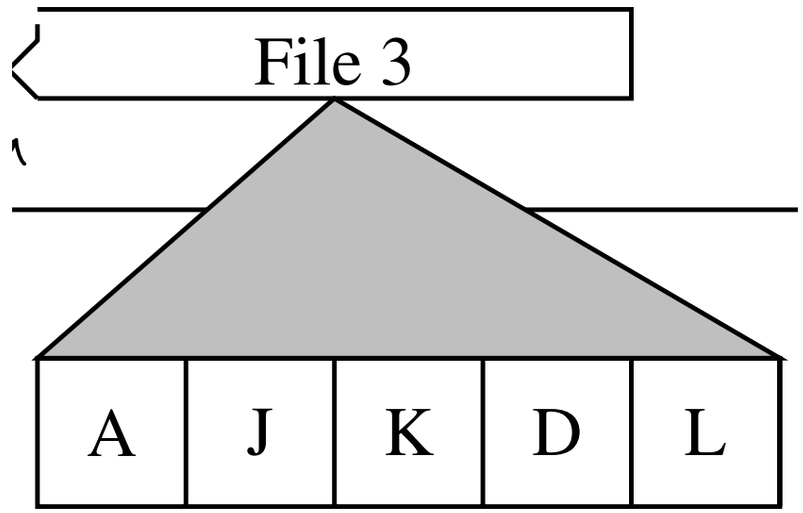
File systems align large files on sector boundaries. We can hash file blocks to identify sectors that match.

Block #	Byte Range	MD5*(block(N))
0	0- 511	**dc0c20abad42d487a74f308c69d18a5a**
1	512-1023	**9e7bc64399ad87ae9c2b545061959778**
2	1024-1535	**6e7f3577b100f9ec7fae18438fd5b047**
3	1536-2047	**4594899684d0565789ae9f364885e303**
4	...	

We can use distinct sectors to find known content.

Method #1 — Full media sampling

- Read & hash every disk sector.
- Lookup hash values in a database of block hashes.
- Distinct hash imply presence of files.
- Advantage: Can find a single sector of target content



Method #2 — Random sampling

- Read & hash randomly chosen sectors.
- Lookup hash values in a database of block hashes.
- Distinct hash implies presence of files.
- Advantage: Can find presence of target content very quickly

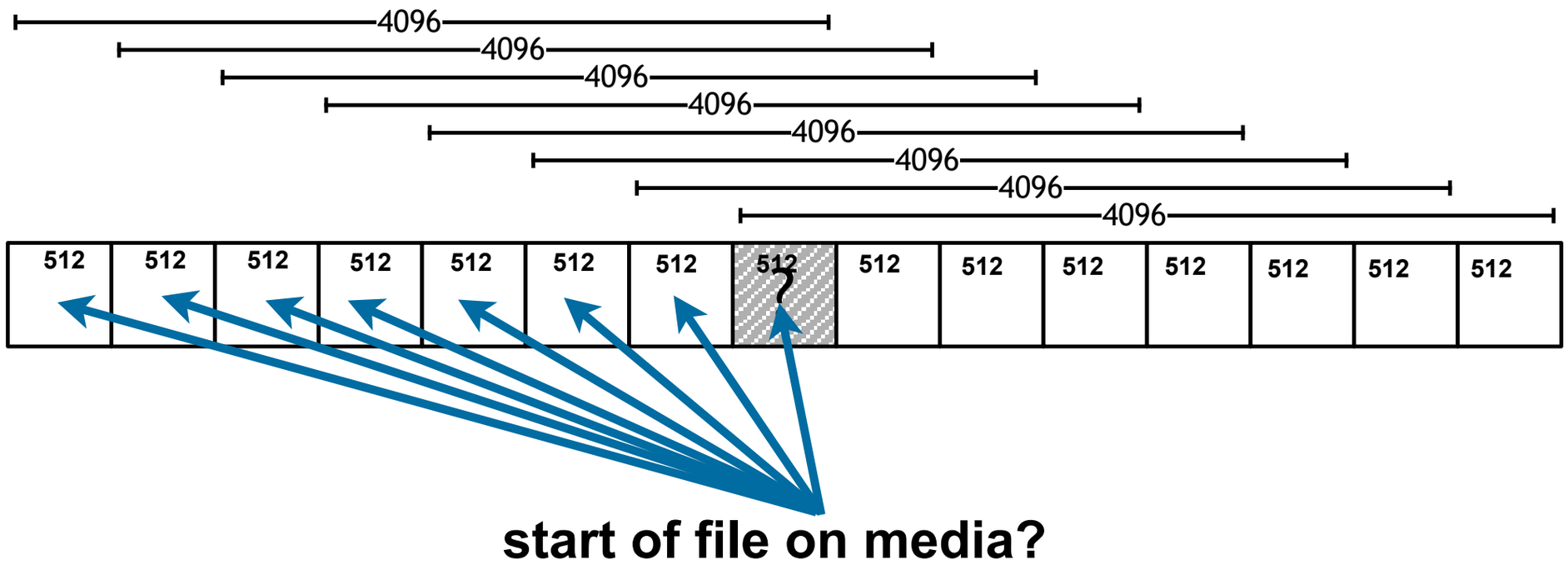
Question: What is the correct block size?

Obvious choices are 512-bytes and 4096-bytes

- 512 — Natural size of today's hard drives
- 4096 — Makes database 1/8th the size.

4096-byte blocks creates *file system alignment uncertainty*.

- The file system probably won't align files at 8-block boundaries.
- Solution: hash 4096-byte window every 512 bytes:



Full media sampling imposes significant hash and database requirements.

1TB data in 208 minutes

- ≃ 80 Mbyte/sec
- ≃ 150,000 512-byte sectors/sec
- ≃ 150,000 database lookups/sec

By combining a Bloom filter & database, we can perform up to 2.7M TPS on low-cost hardware

Table 2. Total transactions per second (TPS) for best execution.

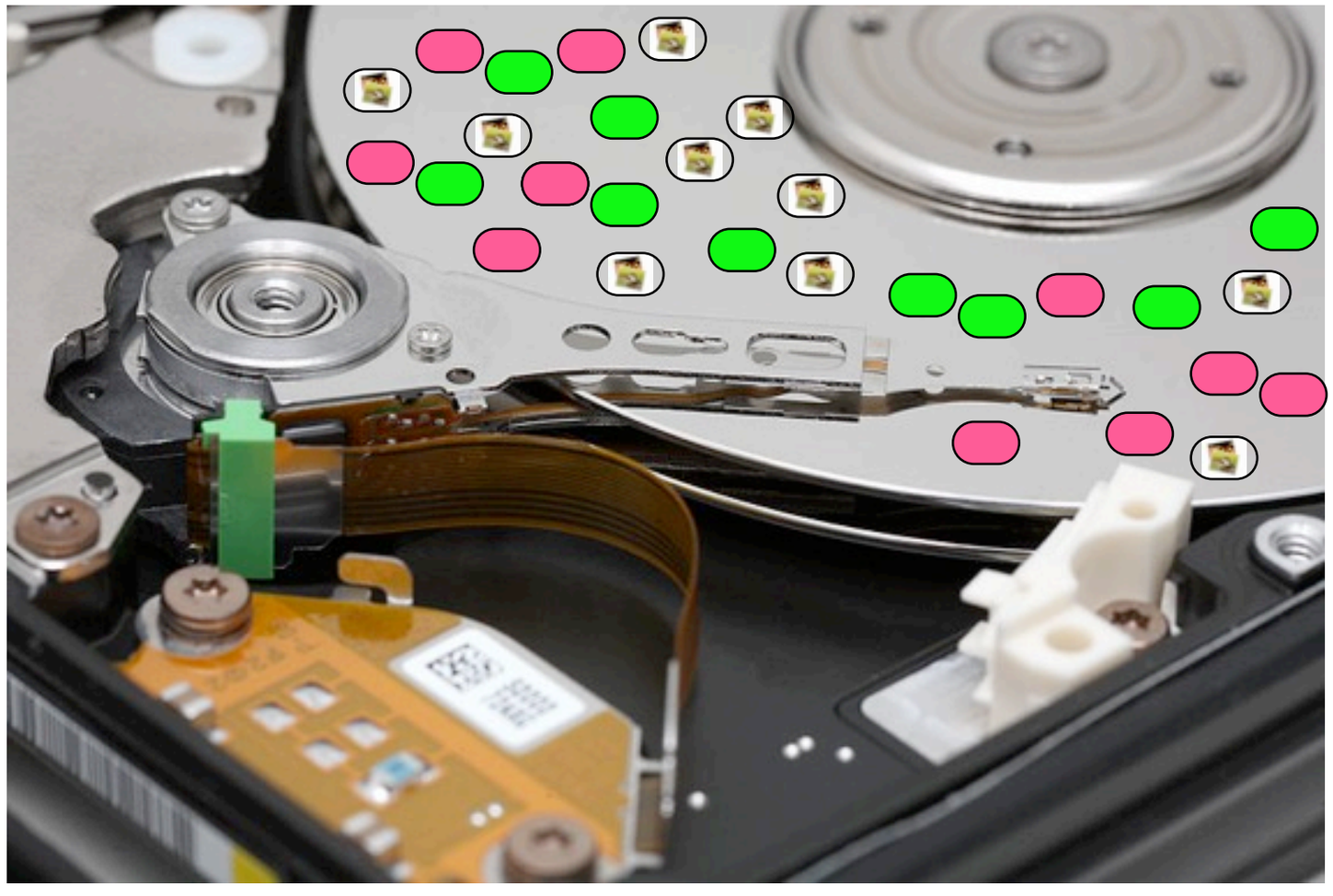
Bloom filter			Database		TPS at 1 M lookups		TPS at 1,200 seconds	
k	*M*	Size	Strategy	Size	Present	Absent	Present	Absent
100 million records								
3	31	257 MiBytes	B-tree (preload)	2.3 GiBytes	35.3 K	49.5 K	161.3 K	1.8 M
3	31	257 MiBytes	B-tree	2.3 GiBytes	11.6 K	565.8 K	156.8 K	2.3 M
3	31	257 MiBytes	Hash map	5.3 GiBytes	13.9 K	656.9 K	641.9 K	3.0 M
3	31	257 MiBytes	Flat map	2.2 GiBytes	28.2 K	746.9 K	356.4 K	2.6 M
3	31	257 MiBytes	Red/black tree	6.0 GiBytes	12.9 K	694.5 K	187.0 K	2.7 M
1 billion records								
3	34	2.1 GiBytes	B-tree (preload)	23 GiBytes	2.2 K	6.1 K	3.6 K	23.1 K
3	33	1.1 GiBytes	B-tree	23 GiBytes	2.6 K	85.8 K	3.7 K	114.9 K
3	33	1.1 GiBytes	Hash map	57 GiBytes	–	–	0.3 K	3.1 K
3	34	2.1 GiBytes	Flat map	22 GiBytes	–	–	0.4 K	4.0 K
3	33	1.1 GiBytes	Red/black tree	60 GiBytes	–	–	0.1 K	1.4 K

Hardware: 8GiB Laptop; 250GB external SSD.

— *"Distinct sector hashes for target file detection," Young, Garfinkel, Foster &*

For random sampling, we will read random blocks of the drive and look for distinct sector hashes.

This work is an outgrowth of our earlier work on random sampling….



Can you measure the contents of a 1TB drive in 10 minutes?

Data on computers is stored in fixed-sized sectors.

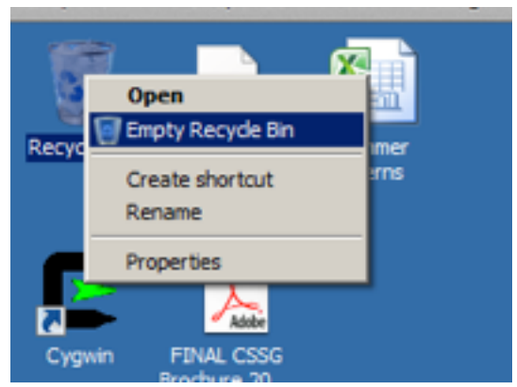
Data in a sector can be resident:

Resident Data

user files
email messages
[temporary files]

Files can be “deleted” but the data remains:

Deleted Data

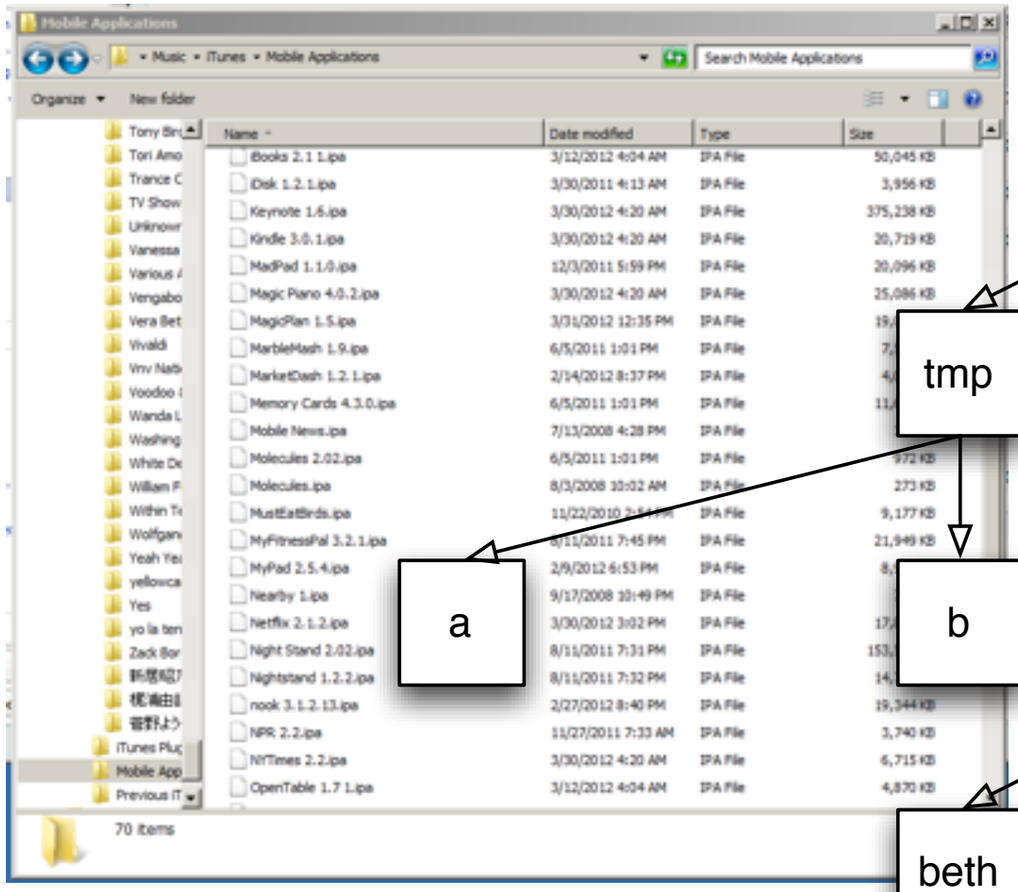


Sectors can be wiped clean:

No Data

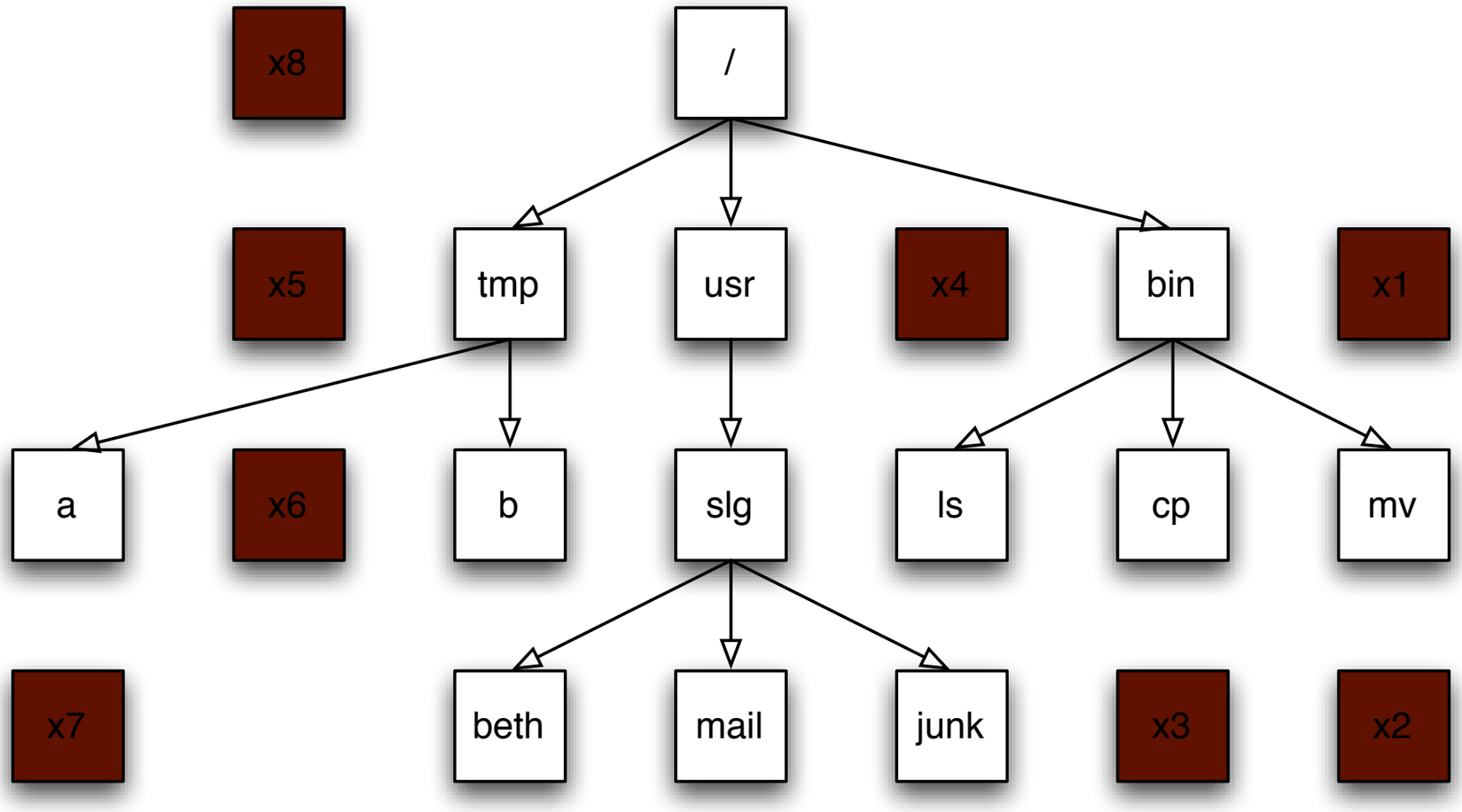
blank sectors

Resident data is the data you see from the root directory. e.g. “allocated” files.



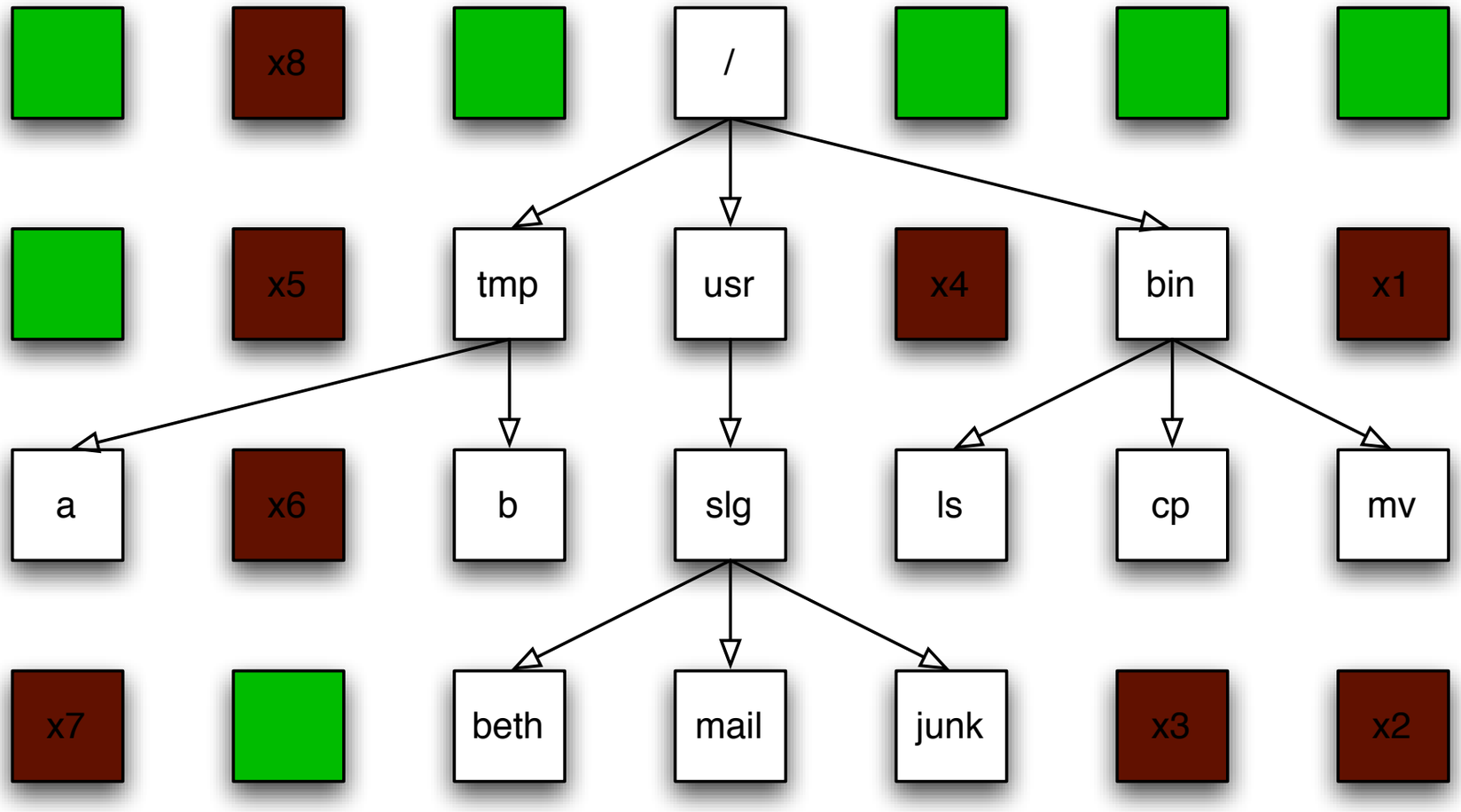
Resident Data

“Deleted data” is on the disk, but can only be recovered with forensic tools.



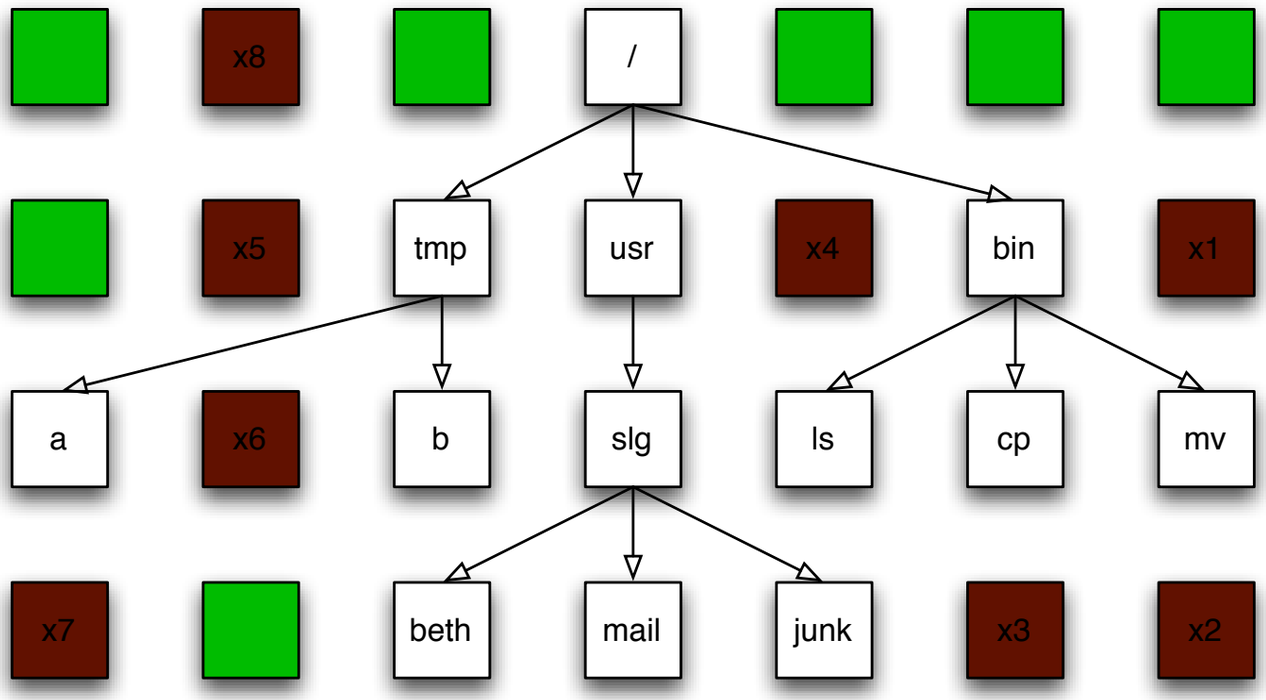
Deleted Data

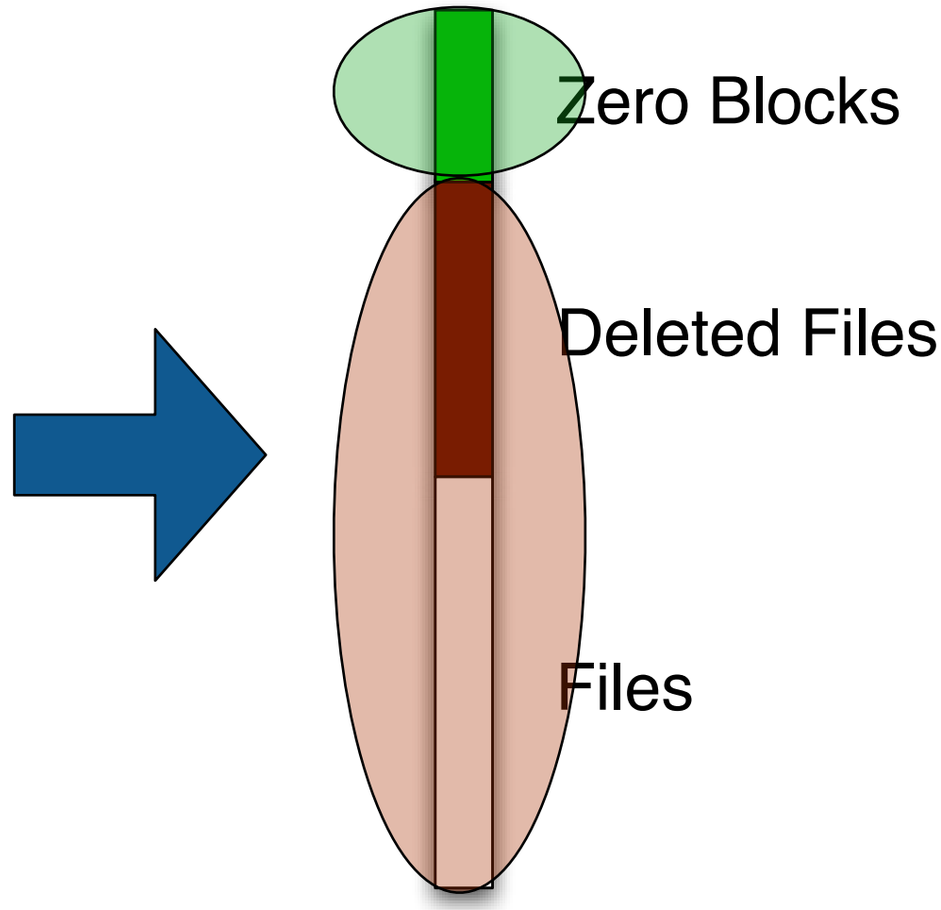
Some sectors are blank.
They have “No data.”



No Data

Sampling can’t distinguish *allocated* from *deleted* data.





Sampling can tell us if there is a likelihood that known data is on the

Challenge for *forensic sampling*: interpreting each sector

"What data do you have?"

- Easy:

```
0000000: ffd8 ffe0 0010 4a46 4946 0001 0201 0048  ......JFIF.....H
0000010: 0048 0000 ffe1 1d17 4578 6966 0000 4d4d  .H......Exif..MM
0000020: 002a 0000 0008 0007 0112 0003 0000 0001  .*..............
0000030: 0001 0000 011a 0005 0000 0001 0000 0062  ...............b
0000040: 011b 0005 0000 0001 0000 006a 0128 0003  ...........j.(..
0000050: 0000 0001 0002 0000 0131 0002 0000 001b  .........1......
0000060: 0000 0072 0132 0002 0000 0014 0000 008d  ...r.2..........
0000070: 8769 0004 0000 0001 0000 00a4 0000 00d0  .i..............
0000080: 0000 0048 0000 0001 0000 0048 0000 0001  ...H.......H....
0000090: 4164 6f62 6520 5068 6f74 6f73 686f 7020  Adobe Photoshop
00000a0: 4353 2057 696e 646f 7773 0032 3030 353a  CS Windows.2005:
00000b0: 3035 3a30 3920 3136 3a30 313a 3432 0000  05:09 16:01:42..
00000c0: 0000 0003 a001 0003 0000 0001 0001 0000  ................
00000d0: a002 0004 0000 0001 0000 00c8 a003 0004  ................
00000e0: 0000 0001 0000 0084 0000 0000 0000 0006  ................
00000f0: 0103 0003 0000 0001 0006 0000 011a 0005  ................
```

- Hard:

```
000a000: 0011 fa71 57f4 6f5f ddff 00bd 15fb 5dfd  ...qW.o_......].
```

An analogous problem: Can we use statistical sampling to verify wiping?

Many organizations discard used computers.

Can we verify if a disk is properly wiped in 5 minutes?

Simple solution:

- 1. Read a random sector
  - —*If there is data, the drive is not wiped.*
- 2. Repeat until satisfied.

A 1TB drive has 2 billion sectors.
What if we read 10,000 and they are all blank?

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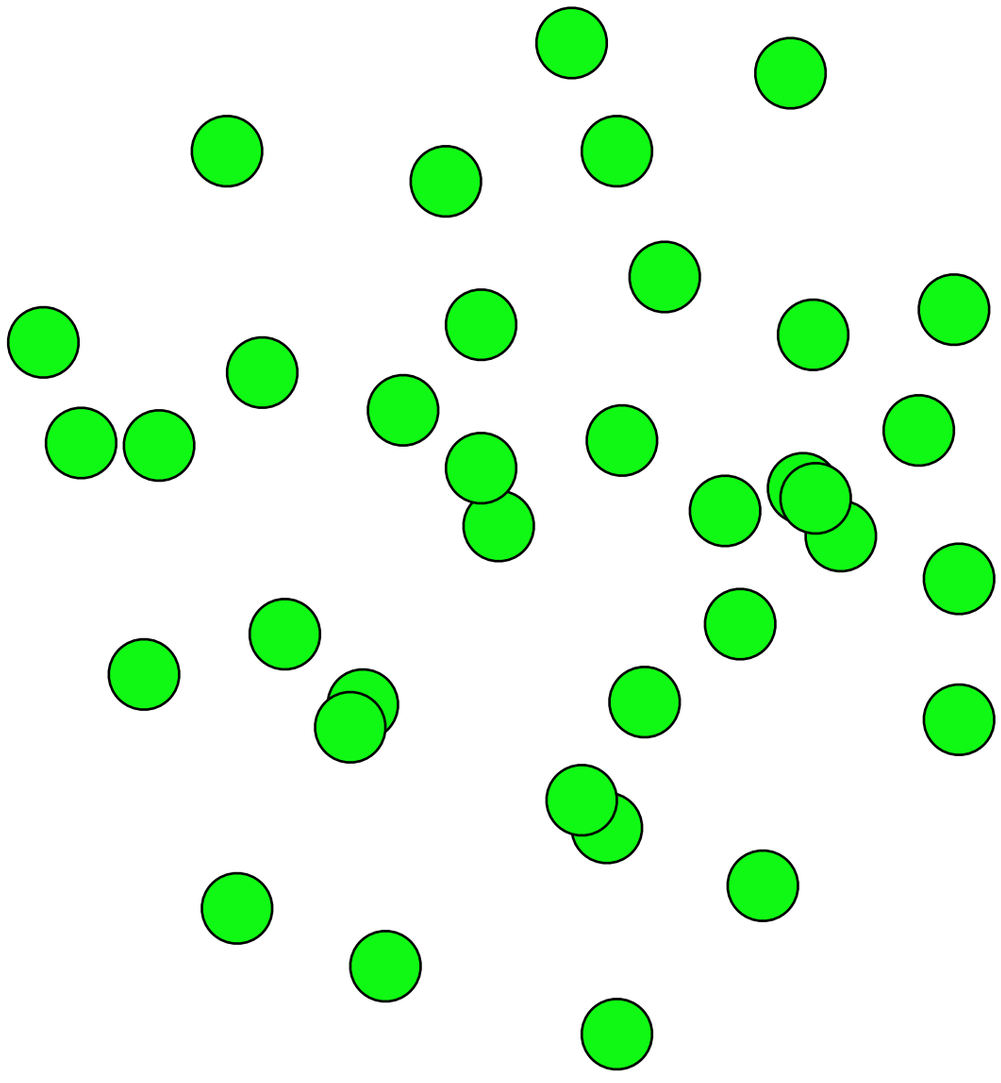
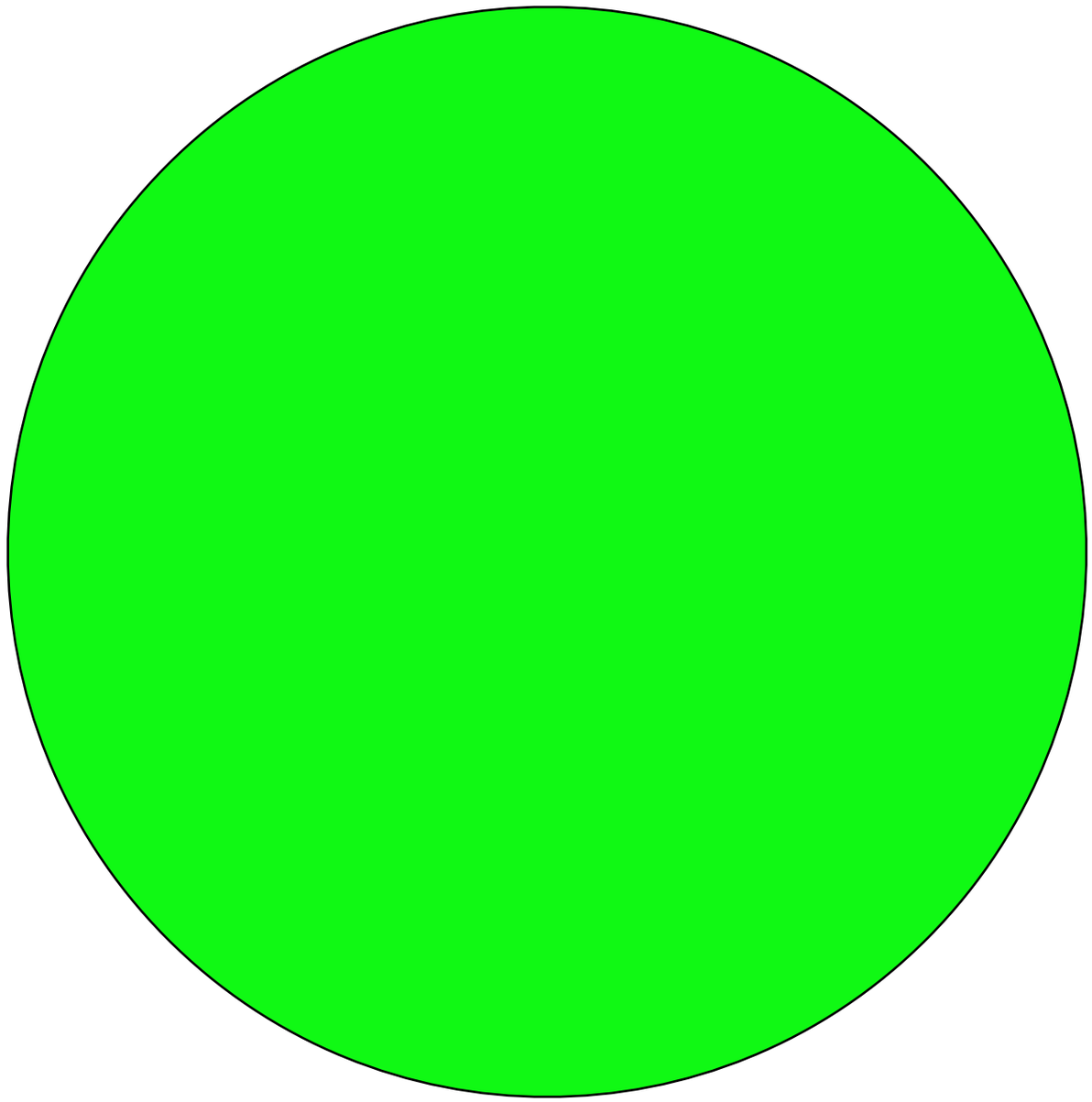


A 1TB drive has 2 billion sectors.
What if we read 10,000 and they are all blank?

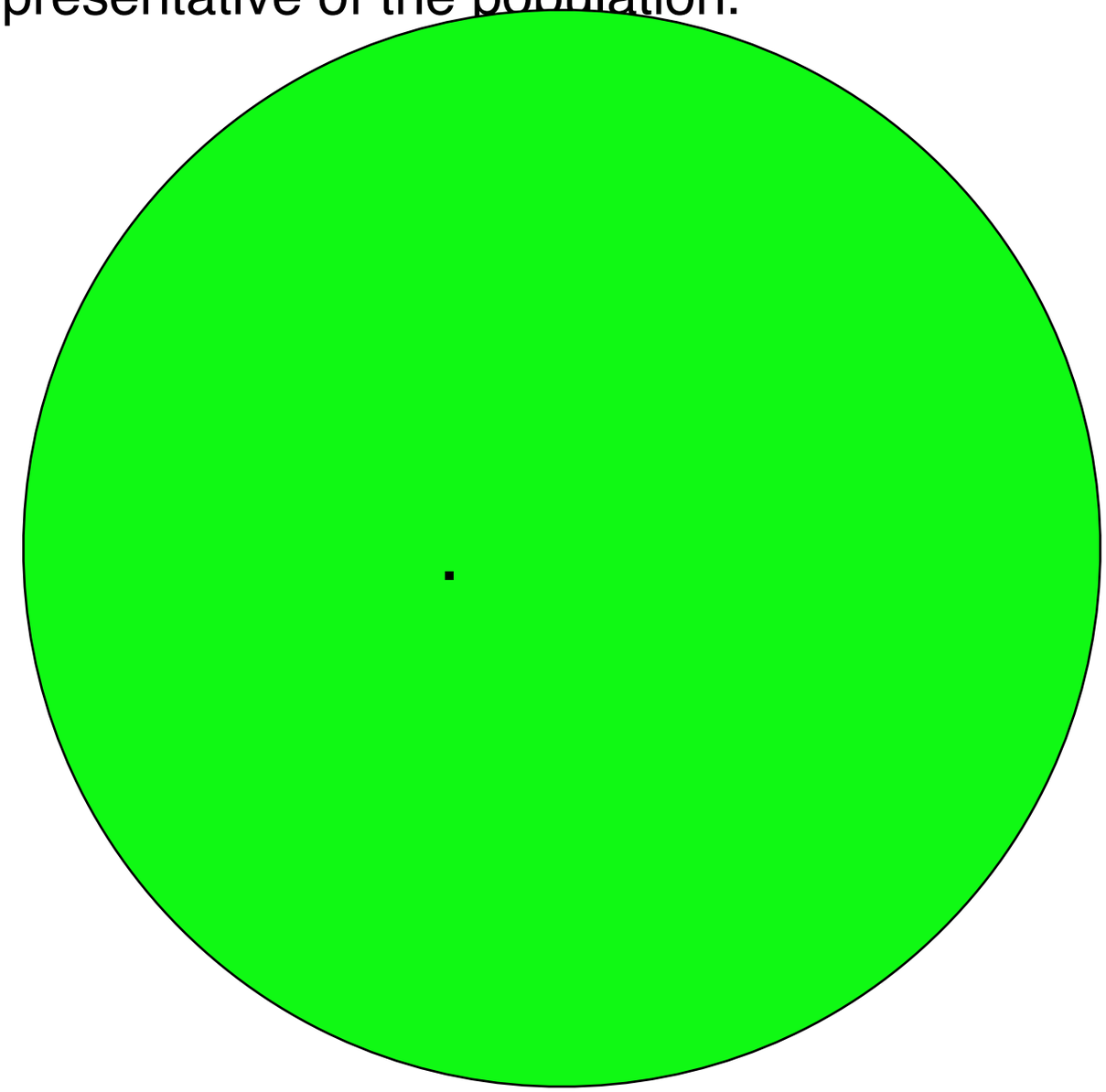


Chances are good that they are all blank.

Random sampling *won't* find a single written sector.

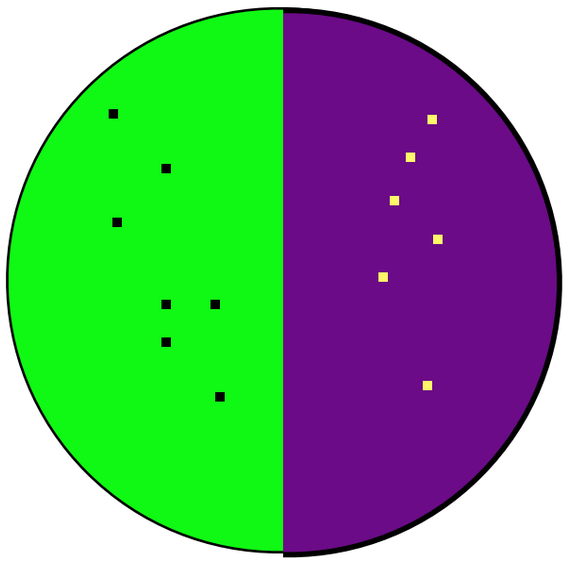
If the disk has 1,999,999,999 blank sectors (1 with data)

- The sample is representative of the population.



If half of the sectors are blank...

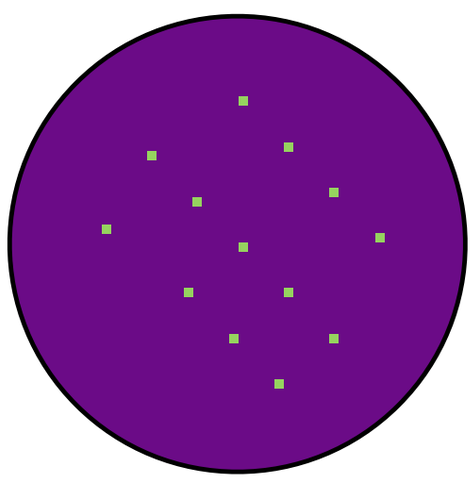
Sectors	Blank	Data
Sampled	5,000 (50%)	5,000 (50%)
Total:	1,000,000,000 (50%)	1,000,000,000 (50%)



The distribution of the data *does not matter* if sampling is random.

What if the the sampled sectors *are the only blank sectors?*

Sectors	Blank	Data
Sampled	10,000 (100%)	0 (0%)
Total:	10,000 (0.0005%)	1,999,990,000 (99%)



If the the only sectors read are blank...

- *We are incredibly unlucky.*
- *Somebody has hacked our random number generator!*

This is an example of the "urn" problem from statistics

Assume a 1TB disk has 10MB of data.

- 1TB = 2,000,000,000 = 2 Billion 512-byte sectors!
- 10MB = 20,000 sectors

Read just 1 sector; the odds that it is blank are:

$$\frac{2,000,000,000 - 20,000}{2,000,000,000} = .99999$$

This is an example of the "urn" problem from statistics

Assume a 1TB disk has 10MB of data.

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- 10MB = 20,000 sectors

Read just 1 sector; the odds that it is blank are:

$$\frac{2,000,000,000 - 20,000}{2,000,000,000} = .99999$$

Read 2 sectors. The odds that both are blank are:

$$(\frac{2,000,000,000 - 20,000}{2,000,000,000})(\frac{1,999,999,999 - 20,000}{2,000,000,000}) = .99998$$

first pick

second pick

Odds we may have missed something

The more sectors picked, the less likely we are to miss the data….

$$P(X = 0) = \prod_{i=1}^{n} \frac{((N - (i-1)) - M)}{(N - (i-1))} \qquad (5)$$

Sampled sectors	Probability of not finding data
1	0.99999
100	0.99900
1000	0.99005
10,000	0.90484
100,000	0.36787
200,000	0.13532
300,000	0.04978
400,000	0.01831
500,000	0.00673

Table 1: Probability of not finding any of 10MB of data on a 1TB hard drive for a given number of randomly sampled sectors. Smaller probabilities indicate higher accuracy.

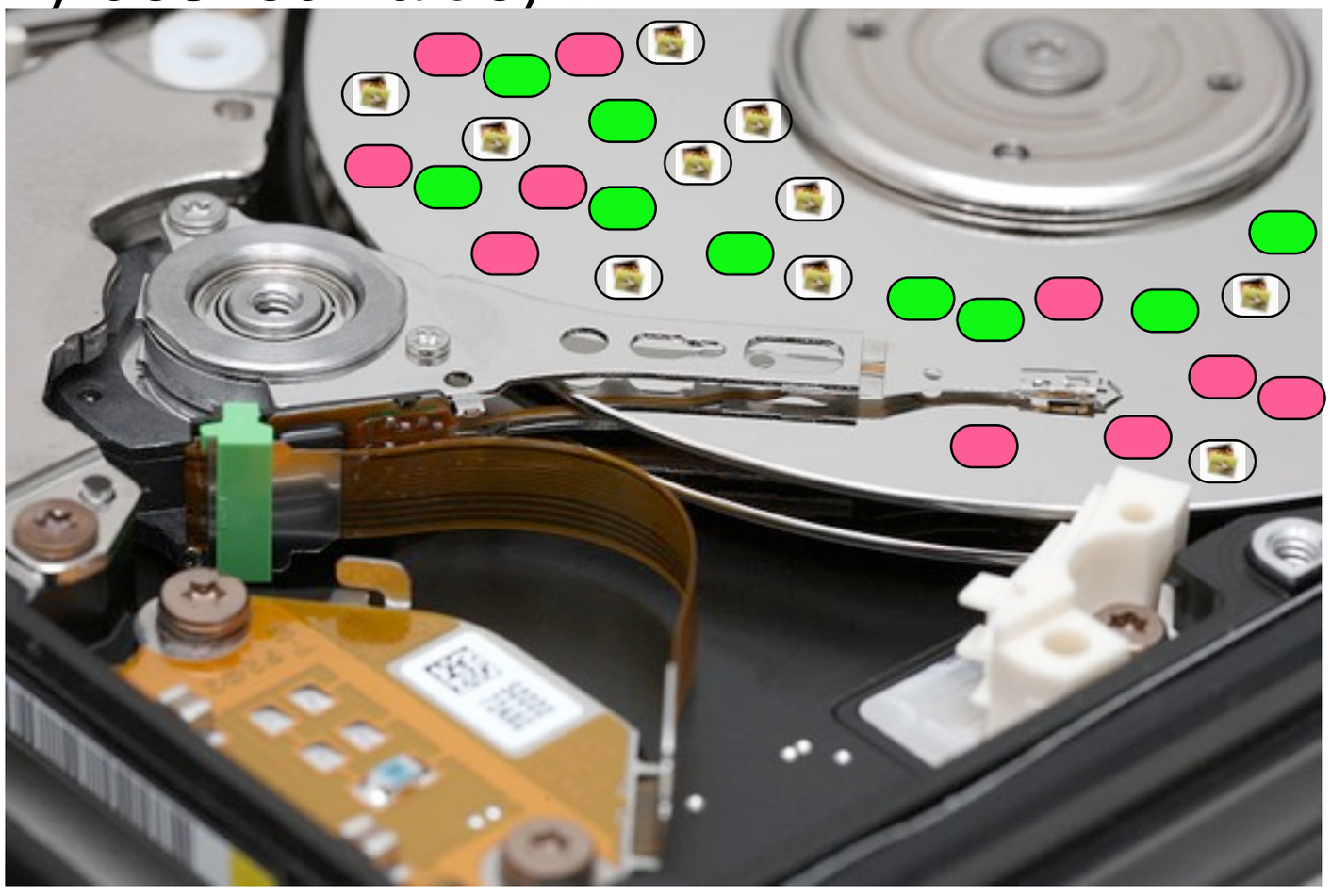
Non-null data		Probability of not finding data
Sectors	Bytes	with 10,000 sampled sectors
20,000	10 MB	0.90484
100,000	50 MB	0.60652
200,000	100 MB	0.36786
300,000	150 MB	0.22310
400,000	200 MB	0.13531
500,000	250 MB	0.08206
600,000	300 MB	0.04976
700,000	350 MB	0.03018
1,000,000	500 MB	0.00673

Table 2: Probability of not finding various amounts of data when sampling 10,000 disk sectors randomly. Smaller probabilities indicate higher accuracy.

- *Pick 500,000 random sectors*
- *If are all NULL, the disk has p=(1-.00673) chance of having 10MB of non-NULL data*
- *The disk has a 99.3% chance of having less than 10MB of data*

The “non-blank content” analysis applies to known content.

1. Randomly sample a 64K chunk.
2. Sector hash a 4K window on 512-byte boundaries (127 hashes)
3. Look up each hash in the database
   - If any hash is found, the known content is present.
4. Repeat until p<0.01 (or any desired value)



Putting it all together, we have a field deployable search system for known content on target media

Method #1: Find a single sector of known content:

- Time to read data & search database: 208 minutes

Technique is file type and file system agnostic

—*JPEG; Video; MSWord; Encrypted PDFs...*

—*provided data is not modified when copied or otherwise re*

Amount of Content	p (prob of missing content)
5 MB	0.3654
10 MB	0.1335
15 MB	0.0488
20 MB	0.0178
25 MB	0.0065

Method 2: Rapidly search for known content (contraband?):

- 1TB subject hard drive.
- 10 min x 60 min/sec x 1000 msec/sec / 3 msec/sample = 200,000 samples
- Searching for a 4K block from a corpus of 512GB
- Requires: 100% recognition of contraband blocks with 0% false positive rate.

Status of this project — “hashdb” (hash database)

“Hashdb” is a C++ package that provides:

- hashdb library — creates, searches, and manages hash databases
- hashdb command — manually building and searching database
- scan_hashdb — A “bulk_extractor” scanner — search for known content in bulk data.

bulk_extractor:

- https://github.com/simsong/bulk_extractor (dev tree)
- http://digitalcorpora.org/downloads/bulk_extractor (downloads)

—*Digital media triage with bulk data analysis and bulk_extractor, Computers & Security 32 (2013),*

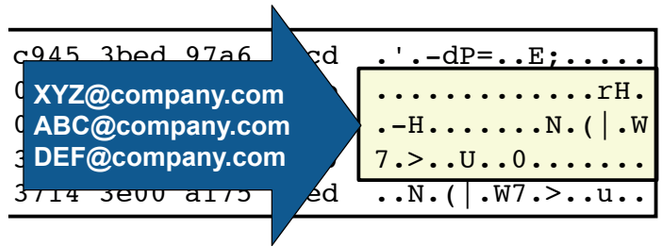
hashdb —

- https://github.com/simsong/hashdb

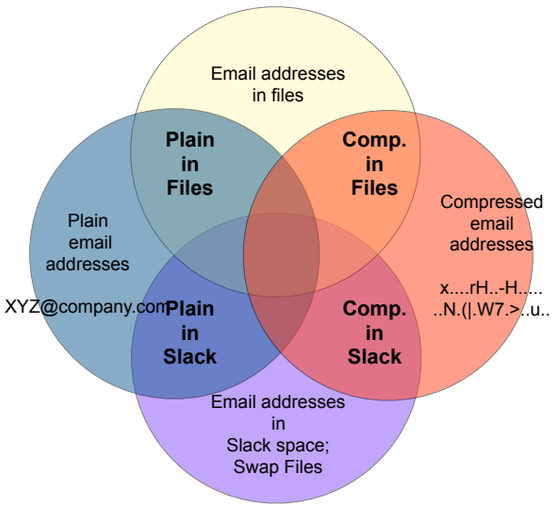
Conclusion

This talk presented two ideas for “triage” of digital media.

1. When searching for content,
it is important to examine *encoded content*.



Our study of 1400 drives found thousands of email addresses that were *only in compressed data.*



2. Sector hashing is an exciting new approach for both rapid and comprehensive searches.

Contact Information:
Simson L. Garfinkel
slgarfin@nps.edu